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A RE-ANALYSIS OF THE COLLABORATIVE KNOWLEDGE TRANSCRIPTS FROM A NONCOMBATANT EVACUATION OPERATION SCENARIO: THE NEXT PHASE IN THE EVOLUTION OF A TEAM COLLABORATION MODEL

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14. ABSTRACT

The goal of this research was to validate the existence and facilitate a better understanding of the stages and underlying macrocognitive processes of team collaboration. Recently, Letsky, Warner, Fiore, Rosen, and Salas (2007) proposed a revised taxonomy and set of definitions for the underlying macrocognitive major processes and subprocesses of team collaboration. For the present research, communication transcripts collected during Warner, Letsky, and Cowen's (2005) second experiment were recoded using the new taxonomy and definitions (Letsky, et al., 2007) and then re-analyzed. The results enabled an examination of the collaboration stages, macrocognitive major processes, and macrocognitive subprocesses in terms of: 1) their consistency and contribution in the team collaboration process, and 2) the next phase in the evolution of a conceptual model of team collaboration.

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SUMMARY

Researchers interested in studying how teams collaborate have been trying for a number of years to develop an empirically based model of team collaboration. The goal of this research was to validate the existence and facilitate a better understanding of the stages and underlying macrocognitive processes of team collaboration. Communication transcripts previously collected during a team collaboration experiment using a Noncombatant Evacuation Operation scenario were used for the present research endeavor. The transcripts were recoded for the underlying macrocognitive major processes and subprocesses of team collaboration using the newest taxonomy and the accompanying revised set of definitions, and then they were re-analyzed.

The results of the re-analyses support the contribution of the four collaboration stages during the process of team collaboration, with the caveat that their consistency appears to be domain dependent. The contribution of all five major macrocognitive processes during team collaboration was also significant; however, whether or not this result is also dependent upon the problem-solving domain is still unknown. The results of the present re-analyses also provided support for some of the macrocognitive subprocesses in terms of both their consistency and contribution. There were also significant differences, depending on the collaboration mode used by the teams, in terms of the collaboration stages, macrocognitive major processes, and macrocognitive subprocesses. The next phase in the evolution of a conceptual model of team collaboration is proposed and areas for future research are also discussed.

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INTRODUCTION

Team collaboration and team problem solving, whether in an educational environment, in a work setting, or during military operations, have been studied for many years. However, the "advent of global networking brings the promise of greatly expanded collaboration opportunities - both for learning and for working together without geographic limitations" (Stahl, 2006, p. 285). Team collaboration tasks, such as learning or problem solving, through a computer-mediated environment, such as the World Wide Web, require the facilitation of communication between team members who may be located separately geographically. Team members may also need to communicate over long periods of time, and not necessarily continually. It is important that the different forms of communication that are needed (e.g., threaded discussion, picture sharing, whiteboard, etc.), depending on the task involved as well as both geographic and temporal difference considerations be supported by the system (Stahl, 2006). In order to determine the most useful forms of communication for various types of tasks, and to facilitate the best possible designs for team collaboration tools, a good model of team collaboration is needed.

Computer-supported collaboration tools have enormous potential to facilitate learning, communication, problem solving, and to improve our lives in general. Unfortunately, the software design process that supports the necessary forms of communication for various tasks is a difficult one. One obstacle hindering the development process is the lack of a clear understanding of the underlying mechanisms employed by teams to collaborate effectively (Stahl, 2006). A number of researchers are studying this area (e.g., Cooke, Kiekel, Salas, Stout, Bowers, and Cannon-Bowers, 2003; Hutchins, 2008; Warner, Biron, and Burkman, 2008; Warner and Wroblewski, 2004, 2005, 2006) and through such empirical research, a clearer understanding of team collaboration should evolve.

Researchers in the field of team collaboration have proposed a number of models of team collaboration (e.g., Cooke, 2005; McNeese, Rentsch, and Perusich, 2000; Orasanu and Salas, 1992; Stahl, 2000, 2006). The Cognitive Model of Team Collaboration proposed by Warner, Letsky, and Cowen (2005), shown in figure 1, is based on team collaboration stages and macrocognitive processes and has undergone an empirical research based evolution since its early conceptualization in 2002 (see Warner and Letsky, in press). Warner, Letsky, and Cowen's (2005) early research used a murder mystery scenario and a Noncombatant Evacuation Operation (NEO) scenario to investigate team collaboration and problem solving. The researchers used the murder mystery for the first experiment in order to investigate two variables: 1) face-to-face versus asynchronous-distributed collaboration mode and 2) homogeneous versus heterogeneous knowledge distribution. For the second experiment, the researchers decided to use an NEO scenario in order to investigate both face-to-face and asynchronous-distributed team collaboration further. During this experiment, the researchers also examined static versus dynamic knowledge uncertainty.

Unlike the murder mystery scenario that had a fixed solution, the NEO scenario created by Warner, Letsky, and Shuck (2004) included numerous possible solutions that varied in terms of how optimal they were when compared to those planned by experts. (The NEO scenario will be discussed more in a later section.) The most significant finding in terms of the differences between these two different types of solutions was that teams solving fixed solution collaborative problems (e.g., the murder mystery scenario) did not go through the Outcome Evaluation and Revision stage. However, teams that collaborated on problems where they needed to develop optimized solutions (e.g., the NEO scenario) spent a significant amount time in each of the four stages outlined in the model (Warner, Letsky, and Cowen, 2005).

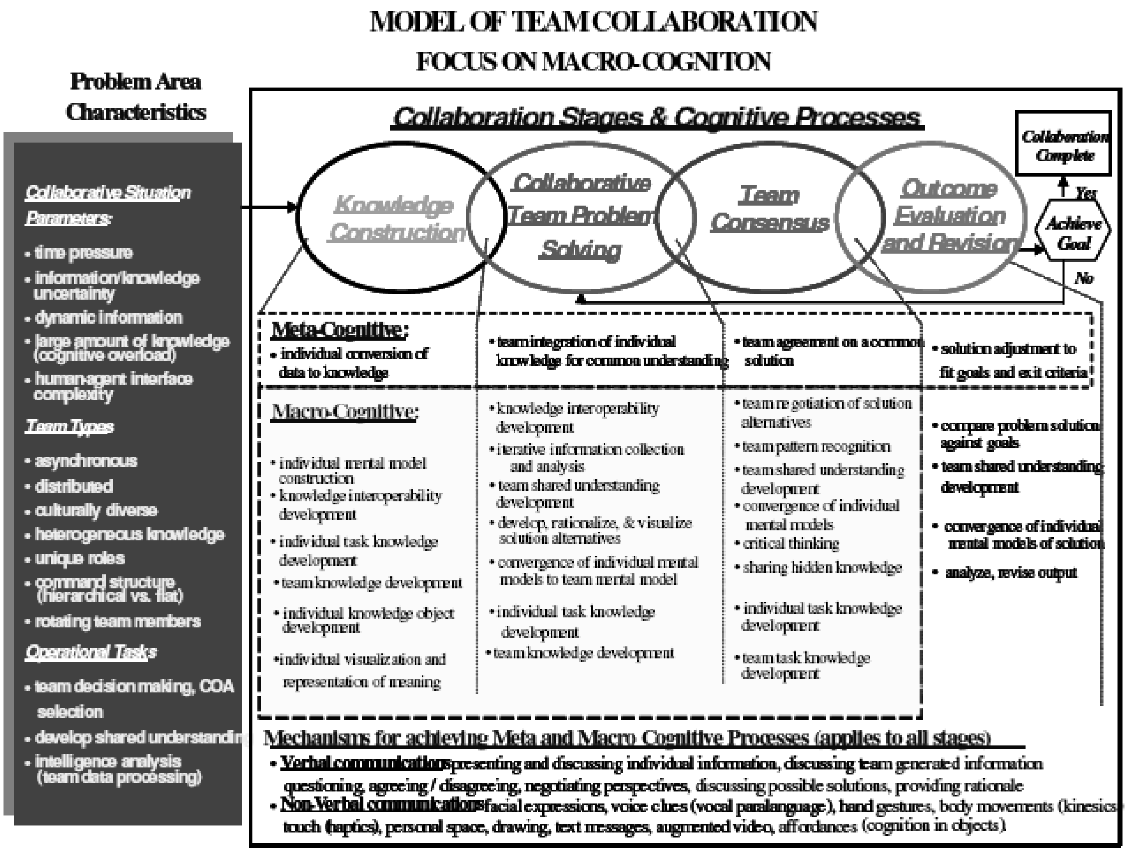

Figure 1: Warner, Letsky, and Cowen's (2005) Model of Team Collaboration

Recently, a number of team collaboration researchers (Letsky, Warner, Fiore, Rosen, and Salas, 2007) proposed some revisions to the Warner, Letsky, and Cowen (2005) model of team collaboration and a corresponding new taxonomy. The new taxonomy of team collaboration that Letsky, and colleagues proposed is shown in figure 2. It includes all 4 of the team collaboration stages (these remained unchanged), 5 new major macrocognitive processes, and 22 macrocognitive subprocesses (see Letsky, et al., 2007), and is the basis for the present re-analysis.

Major Macrocognitive Processes (Shaded) and Sub-Macrocogitive Processes	**Collaboration Stages**			
	Knowledge Construction	**Team Problem Solving**	**Team Consensus**	**Evaluation and Revision**
Individual Knowledge Building				
Iterative Information Collection				
Individual Task Knowledge Development				
Individual Mental Model Development				
Team Knowledge Building				
Pattern Recognition and Trend Analysis				
Team Mental Model Development				
Recognition of Expertise				
Sharing Unique Knowledge				
Uncertainty Resolution				
Knowledge Interoperability				
Developing Shared Problem Conceptualization				
Visualization and representation of meaning				
Building common ground				
Knowledge sharing and transfer				
Team Shared Understanding				
Team Consensus Development				
Critical thinking				
Mental simulation				
Intuitive Decision Making				
Iterative Information Collection				
Solution Option Generation				
Storyboarding				
Team Pattern Recognition				
Negotiation of Solution Alternatives				
Outcome Appraisal				
Feedback Interpretation				
Replanning				
Team Pattern Recognition				

Figure 2: Letsky and Colleagues' (2007) Team Collaboration Taxonomy Constructs

MACROCOGNITION, MACROCOGNITIVE PROCESSES, AND THE NEW TAXONOMY OF TEAM COLLABORATION

"Macrocognition in problem solving teams involves the study of individual and collective knowledge building and utilization of knowledge in the problem solving process" (Letsky, et al., 2007, p. 5). Letsky and colleagues (2007) also emphasized the importance of both the internalized and externalized processes (processes that occur both inside and outside the head, respectively) that occur during team collaboration, and included them in their latest definition of macrocognition.

> "Macrocognition is defined as the internalized and externalized high-order cognitive processes employed by teams to create new knowledge during complex, one-of-a-kind, collaborative problem solving. High-order is defined as the process of combining, visualizing, and aggregating information to resolve ambiguity in support of the discovery of new knowledge and relationships" (Letsky, et al., 2007, p. 7).

In this paper, Letsky and colleagues (2007) provided a revised taxonomy and operational definitions designed to facilitate a better understanding of team collaboration during complex team problem solving. The researchers based the revisions on the lessons learned from the two empirical experiments described by Warner, Letsky, and Cowen (2005). The researchers proposed a set of macrocognitive major processes and nested subprocesses that support each of the team collaboration stages, all of which have been evolving since 2002.

The four stages used to help describe team collaboration are: 1) Knowledge Construction, 2) Collaborative Team Problem Solving, 3) Team Consensus, and 4) Outcome, Evaluation, and Revision (see Letsky, et al., 2007; Warner, Letsky, and Cowen, 2005; Warner and Wroblewski, 2005). However, teams may go through the stages in various orders and an unlimited number of times for each stage. Therefore, the stages are not sequentially ordered, but rather, are dynamic in nature.

For example, a team may begin collaborating on a problem by establishing a plan toward solving the problem. This falls under the Collaborative Team Problem Solving stage. The team may then read, combine, and visualize some information pertinent to a given problem. This falls under the Knowledge Construction stage. The team members may then communicate information about the problem and/or analyze data to try to come up with a solution. This also falls under the Collaborative Team Problem Solving stage. They may then return to reading and combining more information (Knowledge Construction), then begin to negotiate solution options (Team Consensus), and then work as a team to rationalize part of a possible solution (Collaborative Team Problem Solving). After this, the team may try to evaluate the solution they chose against the goal of the problem (Outcome, Evaluation, and Revision). If the team members think that they need to revise any part of the solution (also part of the Outcome, Evaluation, and Revision stage), they may first need to read, combine, and visualize more information or ask other team members questions to help clarify the information. Reading information or asking other team members clarification questions would both fall under the Knowledge Construction stage. The team may also need to use data and information to help justify or rationalize a solution (both classified as Collaborative Team Problem Solving) before reaching final agreement on the solution (Team Consensus). Researchers are still studying exactly how teams flow through the stages and macrocognitive processes (Letsky, et al., 2007). Warner, Letsky, and Cowen (2005) suggested that it might depend on a number of factors. For example, they found team collaboration differences that depended upon the type of team collaboration problem (e.g., fixed solution versus optimum solution) and based upon whether the teams communicated in an asynchronous-distributed or in a face-to-face manner. The level of difficulty of the problem (e.g., the amount of cognitive load required), the amount of shared knowledge between team members (e.g., unique roles), time pressure, and knowledge uncertainty, are some other possibilities that are included in Warner, Letsky, and Cowen's (2005) model that may affect how teams transition through the collaboration stages and macrocognitive processes.

Five new major macrocognitive processes are also included in the new taxonomy: 1) Individual Knowledge Building, 2) Team Knowledge Building, 3) Developing Shared Problem Conceptualization, 4) Team Consensus Development, and 5) Outcome Appraisal (see Letsky, et al., 2007). As is true with the team collaboration stages, these processes occur dynamically, rather than sequentially. While both the stages and major processes described in the model contribute to the collaboration process, the stages are not cognitive in nature. The major processes, however, are cognitive processes and encompass both internalized and externalized processes (see Letsky, et al., 2007).

> "Internalized processes are those higher-order cognitive processes that occur at the individual or the team level, and which are not expressed through external means such as writing, speaking, gesture, and can only be measured indirectly via qualitative metrics (e.g., cognitive mapping, think aloud protocols, multi-dimensional scaling, etc.), or surrogate quantitative metrics (e.g., pupil size, galvanic skin response, fMRI, etc.). Externalized processes are those higher-order cognitive processes that occur at the individual or the team level, and which are associated only with actions that are observable and measurable in a consistent, reliable, repeatable manner or through the conventions of the subject domain having standardized meanings" (Letsky, et al., 2007, p. 7).

In addition to the 5 major macrocognitive processes, Letsky and colleagues (2007) defined and provided descriptions of the 22 macrocognitive subprocesses that nest within the major processes and further act to support the team collaboration stages. Figure 2 is taken from Letsky and colleagues' (2007) paper and represents the taxonomy they proposed.

GOALS OF THE CURRENT RESEARCH

As Letsky and colleagues (2007) stated, one of the lessons learned from Warner, Letsky, and Cowen's (2005) experiments is the "the need to understand the *contribution* and *consistency* of each macrocognitive process across different problem domains…which will provide a deeper understanding of how these processes impact team collaboration performance" (p. 3). In re- analyzing Warner, Letsky, and Cowen's (2005) NEO scenario data, the goal was to provide a better understanding of the contribution of the macrocognitive major processes, and of the contribution and consistency of the subprocesses using the revised taxonomy, which should facilitate a better understanding of team collaboration.

The rationale for choosing the NEO scenario experimental data (Warner, Letsky, and Cowen, 2005) was four-fold. The first reason is that the NEO scenario, as opposed to the murder mystery scenario, produced communication data that spanned across all four team collaboration stages. The second reason is that since the communication data were coded using an earlier taxonomy and definitions (see Warner, Letsky, and Cowen, 2005), a comparison could easily be done between the new and old taxonomies. The third reason for choosing the NEO experimental data involves the method used to create the NEO scenario itself (described in the next section). Finally, as more and more teams need to communicate and collaborate on problems from different locations around the world, results from studies that examine asynchronous and/or distributed collaboration will need to play a more important role in the development of models of team collaboration. Thus, since the original NEO experiment (Warner, Letsky, and Cowen, 2005) examined face-to-face versus asynchronous-distributed modes of communication, it seemed like an advantageous set of data to re-examine.

THE CREATION OF TEAM COLLABORATION PROBLEM SOLVING SCENARIOS

The NEO: Red Cross Rescue Scenario (Warner, Wroblewski, and Shuck, 2004; see appendices A, B, C, and D) was developed for the Office of Naval Research Collaboration and Knowledge Interoperability program in order to facilitate research on team collaboration and problem solving. The researchers developed the scenario with the help of input from military personnel. However, both military and nonmilitary persons can solve the unclassified scenario.

Warner, Wroblewski, and Shuck (2004) also developed a scoring matrix for the final NEO plan (see appendix E). They did this with input from military operational personnel who had experience in actual NEO scenarios. The researchers created the matrix so that they could score each team's final plan, and this score would then serve as an objective measure of team performance for data analysis.

The scenario requires participants to develop a course of action (COA) to rescue three Red Cross workers trapped in a church basement on a fictitious South Pacific Island. Required elements of the final plan include a list of U.S. forces, transportation, weapons, event timeline, and a detailed explanation of the plan. Each team member receives a Mission Statement, data about available U.S. military assets, topographical maps, information about hostile forces in the area, and other descriptors of the island (see appendix A). An experimenter (at the beginning of the session) assigns each team member an "expertise" in one of the three following areas: 1) local intelligence, 2) available weapons, or 3) local environmental issues. The experimenter also provides each team member with the information relevant to his/her "expertise" (see appendices B, C, and D). At the end of the problem solving session, participants submit the final plan. While the NEO is only one example of a complex, event-based scenario that can be used as a foundation for team collaboration experiments (see also Warner, Burkman, and Biron, in press), it seemed ideal to use as a basis for our reanalysis since it was designed specifically to facilitate team collaboration.

METHOD

PARTICIPANTS

A total of 96 undergraduate students from a community college in Southern Maryland served as the participants for the original NEO experiment (see Warner, Letsky, and Cowen, 2005). Participants consisted of 36 men and 60 women, between the ages of 17 to 53 years of age (Mean = 24.13 years, SD = 10.28). Participants in this study received $15 an hour to complete the task (which could last up to 4 hr) and their professor gave them extra credit for their participation.

DESIGN

The experimental design used in the original NEO experiment (see Warner, Letsky, and Cowen, 2005) was a two by two randomized factorial with two levels of each of the two independent variables: 1) collaboration mode (face-to-face versus asynchronous-distributed) and 2) knowledge uncertainty (static versus dynamic). The experimenter randomly assigned students to the conditions. Thirty-two three-member teams completed the experiment and the data collected from all of these teams was the basis for the present re-analysis using the revised taxonomy and definitions proposed by Letsky and colleagues (2007).

Independent Variables. The independent variables were the same as those of the original NEO experimental design (see Warner, Letsky, and Cowen, 2005). The first independent variable, collaboration mode, consisted of two levels: face-to-face and asynchronous-distributed. The face-to-face condition consisted of teams of three participants interacting synchronously with each other around a conference table using verbal communication. The asynchronous-distributed condition also consisted of three member teams. However, the team members interacted with each other from different locations (cubicles separated by partitions located in the same lab) and there was a minimum time delay of 1 sec between text responses. All team communication was through a text-based forum (i.e., modified Electronic Card Wall – EWall; see Keel, 2004, 2005) hosted on IBM laptops through an intranet server. Figure 3 illustrates the modified EWall and the four rooms that team members used to solve the NEO collaborative problem.

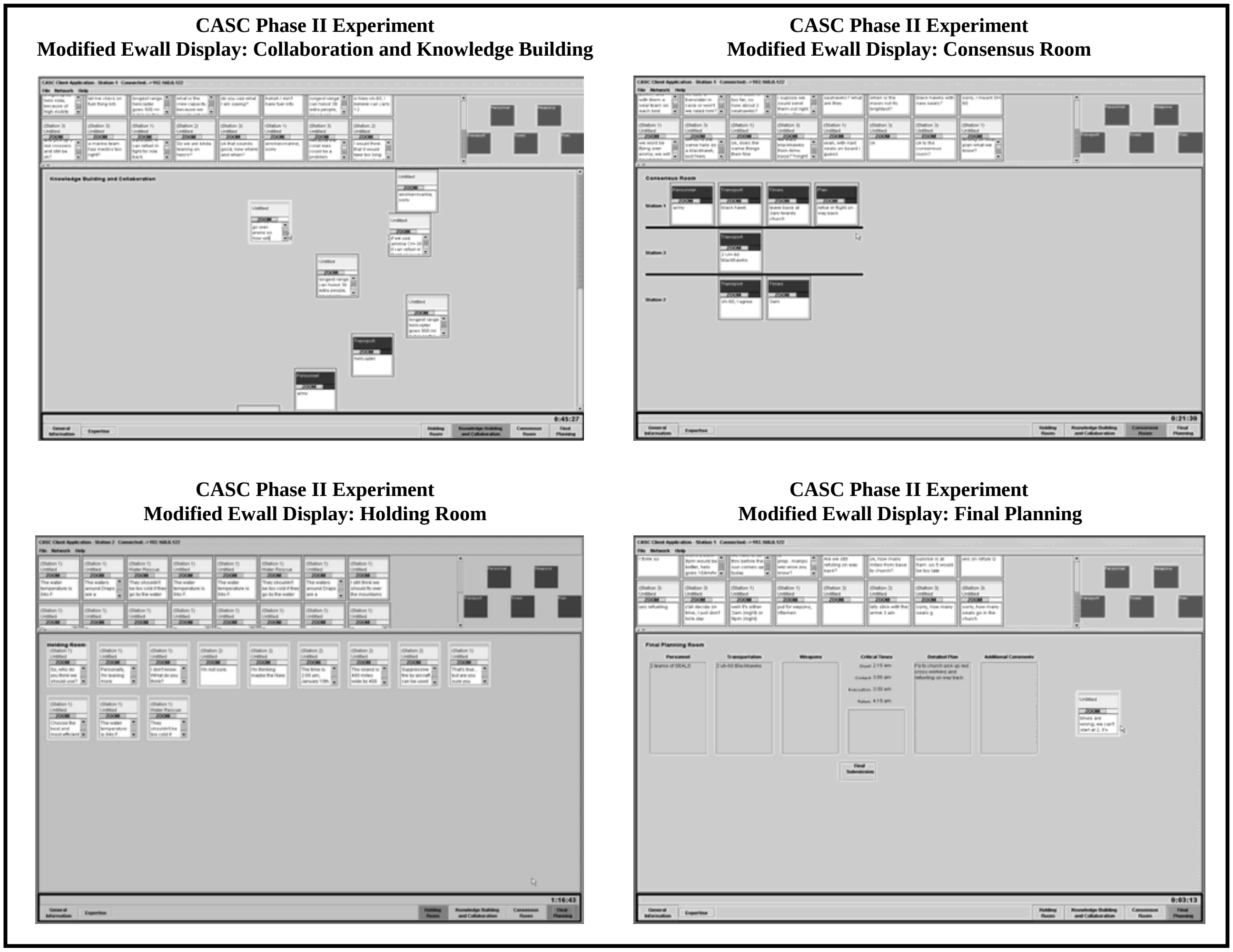

Figure 3: Screen Captures from Modified EWall Program

Collaboration and knowledge building was done in the first display and all team members could see all current text responses (i.e., up to the most recent 25 text cards) from other team members. Cards created prior to the 25 most recent would be placed in the Holding Room where they could be viewed at any time. Team consensus was worked on in the Consensus Room where solution options from each team member could be viewed while solutions were being developed. The team developed the final plan in the Final Planning Room and submitted the plan at the end of the session.

Knowledge uncertainly served as the second independent variable. The first level of the variable was static knowledge, where all information (e.g., background information, rebels, military assets, and weapons or environment expertise information) remains the same throughout the collaborative NEO scenario problem. During the dynamic knowledge condition, 30 min into the collaboration portion of the session, the experimenter provided an “update” in which selected information (e.g., rebel location and weather) was altered (see Warner, Letsky, and Cowen, 2005).

Dependent Variables. Warner, Letsky, and Cowen's (2005) original NEO experiment included five dependent variables: (1) score on the final plan, (2) time to complete the task, (3) time spent in each of the collaboration stages and macrocognitive processes, (4) frequencies of utterances in each of the stages and processes, and (5) transition probabilities between the stages and processes (see Warner, Letsky, and Cowen, 2005). The current re-analysis using the new taxonomy and definitions (see Letsky, et al., 2007) focused on the time spent in each of the team collaboration stages and macrocognitive processes and the transition probabilities between the stages and major processes.

PROCEDURES

Original NEO Experimental Procedure. The original procedure used in the NEO experiment by Warner and colleagues (2005) was as follows. The experimenter instructed each of the 32 teams, each consisting of 3 participants, to work as quickly and accurately as possible to develop a COA for a collaborative problem-solving task, the NEO scenario (see appendices A, B, C, and D; see also Warner, Letsky, and Shuck, 2004). Participants all completed consent forms before beginning the experiment.

Each participant was first given instructions (see appendix F) which included a brief description of the problem they were about to solve, the amount of time they would have to complete the task, and were given the opportunity to ask questions about the task. Participants were then given 20 min to individually read the mission statement, background information, and randomly assigned expertise information (either weapons, intelligence, or environmental). The experimenter then assigned one of the team members to act as the scribe during the experiment. The scribe's task was to fill out the final plan. The teams then had a maximum of 60 min to collaborate in either a face-to-face or an asynchronous-distributed manner and to fill out the final COA plan. The final plan included the following sections: personnel, transportation, weapons, critical times, and the detailed plan (for example, see appendix G).

Team members assigned to the dynamic condition had the updated intelligence and weather information presented to them 30 min into the session. For the face-to-face condition, the experimenter presented the team a typed update that included the new intelligence and weather information (see appendix H). The asynchronous-distributed condition received the same update (also presented 30 min into the session) via the PC server on their IBM laptop workstations.

All of the communication that occurred in the face-to-face condition was audio and video recorded and timed tagged for later transcription; whereas, all the asynchronous-distributed text was recorded, time tagged, and saved via the server. After all teams had been run through the experiment, the communication data were coded by two independent raters on the basis of both the team collaboration stages and the macrocognitive processes based on Warner, Letsky, and Cowen's (2005) then current definitions. (This process will be described in-depth under the section of this report describing the procedure used for the reanalysis.) All of the data collected by Warner, Letsky, and Cowen (2005) was analyzed and the results are summarized in their paper.

Procedure for the Scoring of the Final Plan for the NEO Scenario. As each team worked to solve the solution for the NEO scenario, they were instructed to write out a final plan listing assets used during the operation (personnel, transportation, and weapons), critical times calculated (times of onset, contact, evacuation, and return to base or ship), and a detailed plan describing exactly how the mission would be carried out. The experimenter also gave the teams an opportunity to add any additional comments regarding their final plan. The form in appendix G is an example of an actual team's final plan completed in the previous face-to-face study.

Using the example in appendix G, an explanation of the scoring process with the aid of examples may offer a greater understanding of how the researchers scored each of the final plans. In the first section, the team listed the personnel they would be using on this mission. The team received full points for this portion because they included all the necessary information. For the transportation section, the team noted that they would be using the Seahawk and a C-130 to refuel the Seahawk. They lost two points for this portion because they chose to refuel their aircraft; however, there were other aircraft options that did not require the added risk and time needed to refuel. In the third box, the team listed the weapons they planned to use during the mission. The team in the example properly listed all the necessary weapons and, therefore, received full points for this section.

The final three sections of the final plan move beyond listing the assets and materials and into devising a well-constructed plan of action. The fourth section required the team to list the four critical times of the mission. Onset of operation was defined as the time at which the military leaves the base or ship. Contact referred to the time the military made contact with the Red Cross Workers trapped in the church. The team also needed to include when the military would evacuate the church and the time at which they would return to the base or ship. In the example in appendix G, the time of contact was listed as 5:06 a.m. and the time of evacuation was scheduled to be 5:45. According to the team's plan, the military would be in the church for more than half an hour. However, time was of the essence, and once the military entered the church, they should have moved as quickly as possible and left the area within 30 min. Therefore, the team lost another two points for this violation.

In the detailed plan, the team provided a description of the mission. They also provided additional comments that proved beneficial to their final score. In the detailed plan, the team described how the Red Cross team would be hoisted from the ground and flown back to the ship. The problem with this part of the team's solution was that the team failed to avoid detection because flying over the island would certainly allow the rebels to hear and see the military aircraft, giving them an opportunity to attack. In the additional comments section, the team mentioned that the flight was performed at night to "avoid detection". Avoiding detection is imperative to any Special Operations mission, and the Special Forces of each branch are specifically trained in this area. Since the team addressed avoiding detection but failed to do so by flying so close to the island, they only lost two points. If they had not made this additional note, one additional point would have been deducted, as they would have failed to address possible detection. In addition, the team addressed giving medical attention to the Red Cross workers once they were in the aircraft in the "additional comments" portion of the plan. If they had no mentioned this, the team would have lost an additional five points, since aiding the Red Cross workers is the main priority in this situation.

The team's final score was 94 out of a possible 100 points. See appendix E for a complete matrix delineating point deductions for each planning card. The "ideal" solution is shown in appendix I.

Procedure for the Re-analyses. As was the case with the original NEO experimental data, the communication data needed to be assessed in terms of the team collaboration stages. Once again, two independent raters coded the transcripts for the team collaboration stages. The process began with each of the new raters familiarizing themselves with the definitions and examples for the four team collaboration stages. Then each rater went through a subset of the communication transcripts (10 teams total - 5 face-to-face and 5 asynchronous-distributed). For each line of communication data (utterance), each rater independently had to decide which of the four team collaboration stages best described that line of data and label/code the line based on that decision. The interrater reliability between the two raters was then calculated and compared with the score obtained from the two original raters and found to be statistically equivalent (reported in the Results section). Thus, since the old and new taxonomies did not differ in terms of the team collaboration stages, the original raters' coded data were used for the remainder of the analyses.

The next task for the two raters was to go through the new taxonomy and definitions (see Letsky, et al., 2007) and make sure that adequate examples existed for the processes that carried over from the earlier taxonomy or were added for all of the new definitions for both the macrocognitive major processes and subprocesses (for all definitions and examples, see appendices J and K). The examples were all agreed upon by both raters to be useful for future coding based on the definitions and were taken from the communication transcripts from the original NEO experiment (Warner, Letsky, and Cowen, 2005). For three of the macrocognitive subprocesses, an additional step was taken before the two raters began coding the transcripts. For these three subprocesses (Storyboarding, Mental Simulation, and Building Common Ground), the researchers added operational definitions that could be used to measure these processes given the communication data (see appendix K). These measures, given the lack of orthogonality with the other subprocesses and their method of calculation, became secondary measures since they were dependent upon other subprocesses for their measurement.

The transcripts were coded independently by the two raters once they had gone over all of the definitions and agreed upon the new examples. Each rater went through each line of text (that either corresponded to transcribed spoken statements or typed text used to communicate during the experiment) and, on the first pass through, determined which of the macrocognitive major processes to assign. In order to accomplish this, raters looked at, not only each line of text individually, but they also considered the context (e.g., surrounding lines of text that related to the same topic) as well. Based on the definitions and examples, the raters were looking for reasons to select one process over the others. Some of the criteria that aided the raters in this process included: whether or not the line(s) included question asking and answering, whether or not someone had suggested a solution option, whether or not the team was discussing goals of the problem, and whether or not the participant(s) referred to a visual aid, such as a map or drawing. For example, if all three team members were involved in raising and discussing a solution to the problem, this falls under the macrocognitive major process of Team Consensus Development. If two team members were discussing the rules they must follow to solve the problem or the goals of the problem (without asking questions), raters would code this as Developing Shared Problem Conceptualization. Also taken into consideration was how many of the three team members were involved in discussing the current topic considering that several of the definitions (e.g., Team Knowledge Building) must include all three team members (see appendix J), whereas others do not (e.g., Individual Knowledge Building). However, if after considering all of the five macrocognitive major processes a rater determined that none of them accurately reflected a line of text, they labeled the line as "miscellaneous". After the two raters independently coded all of the transcripts for the macrocognitive major processes, they repeated the same process for the subprocesses. Once this was completed, they began the process of reconciling the lines in the transcript for which the two raters disagreed on the appropriate code.

In order to reconcile any coding differences between the raters in the transcripts, the two raters convened and went through and discussed each line of text where a disagreement occurred. For each of these instances, raters discussed their rationales for the code that each had chosen, the definition(s), examples, similar occurrences from the transcripts, and anything else pertinent until a consensus was reached regarding the final decision as to what the line should be coded.

RESULTS

Warner, Letsky, and Cowen (2005), in their original analyses used a 2x2 ANOVA to analyze the total time to complete the task across collaboration modes and the level of knowledge uncertainty along with the accuracy of the final plan and the frequency of utterances. The researchers found that there were no significant differences between the face-to-face and asynchronous-distributed conditions in the total amount of time to complete the task, $F=0.26$, $p=0.62$; or the level of knowledge uncertainty, $F=1.88$, $p=0.18$. The interaction was also found not to be significant, $F=0.13$, $p=0.72$. There was no significant difference in the accuracy of the final plan between the two collaboration modes, $F=2.37$, $p=0.14$, or knowledge uncertainty, $F=0.07$, $p=0.80$. The interaction between them was not significant, $F=0.37$, $p=0.55$. There was a significant difference found between the face-to-face and the asynchronous-distributed teams, $F=96.50$, $p < 0.001$. The researchers also calculated the mean numbers of utterances across the conditions. For the face-to-face teams, the mean number of utterances was 847.31, whereas it was only 91.13 for the asynchronous-distributed teams. Once again, there were no significant differences found regarding the variable of knowledge uncertainty, $F=2.06$, $p=0.16$, or the interaction, F=2.73, p=0.11. These results were all reported in Warner, Letsky, and Cowen's (2005) paper.

THE TEAM COLLABORATION STAGES

As was mentioned earlier, the interrater reliability for the team collaboration stages between the two new raters (0.80) was not found to be significantly different from the reliability calculated for the two raters used for the original analyses (0.80). Therefore, the original data labels were used and the percentage of total time spent in each of the stages was calculated.

A 2x2 ANOVA was used to re-analyze the percentage of total time spent in each of the team collaboration stages across collaboration modes and the level of knowledge uncertainty. There was no significant main effect found for the two collaboration modes, F=1.54, p=0.22. There was also no significant difference found for knowledge uncertainty, F=0.45, p=0.77, and the interaction was not significant, F=0.76, p=0.56. As for the univariate results for each of the stages, there was a significant difference between the two collaboration modes in the mean percentage of time spent in each collaboration stage. The face-to-face teams spent more time in Knowledge Construction than the asynchronous-distributed teams, F=6.51, $p < 0.01$. The asynchronous-distributed teams spent significantly more time in the Collaborative Team Problem Solving stage than the face-to-face teams, F=5.60, $p < 0.05$. There were no other significant main or interaction effects for collaboration stages. These dependent variable univariate results were also reported in Warner, Letsky, and Cowen's (2005) paper.

THE MACROCOGNITIVE MAJOR PROCESSES

The interrater reliability between the two raters based on their coding of the macrocognitive major processes was calculated. The interrater reliability was 0.82. Then, the percentage of time spent in each of the major macrocognitive processes was calculated and used for the remainder of the analyses, as was done with the team collaboration stages.

A 2x2 ANOVA was used to analyze the percentage of total time spent in each of the macrocognitive major processes across collaboration modes and the level of knowledge uncertainty (see figure 4). Overall, the only significant difference was found between the two collaboration modes, F=15.88, $p < 0.001$. In comparisons between the major macrocognitive processes, the only significant differences were found across the collaboration modes. Face-to-face teams spent significantly more time than asynchronous-distributed teams in the Team Knowledge Building process, F=29.53, $p < 0.001$. The asynchronous-distributed teams were significantly more likely to spend a greater percentage of time engaged in the Developing Shared Problem Conceptualization process than face-to-face teams, F=8.62, $p < 0.01$. No other significant differences were found.

The data were then transformed to examine how the major processes were nested within each of the team collaboration stages. A 2x2 ANOVA was used to analyze the percentage of total time spent in each of the major processes during each of the collaboration stages across collaboration modes and the level of knowledge uncertainty. There was a significant difference across collaboration mode, F=6.48, $p < 0.01$. There was no significant difference for knowledge uncertainty, F=0.96, p=0.55. The interaction was not significant, F=0.61, p=0.83.

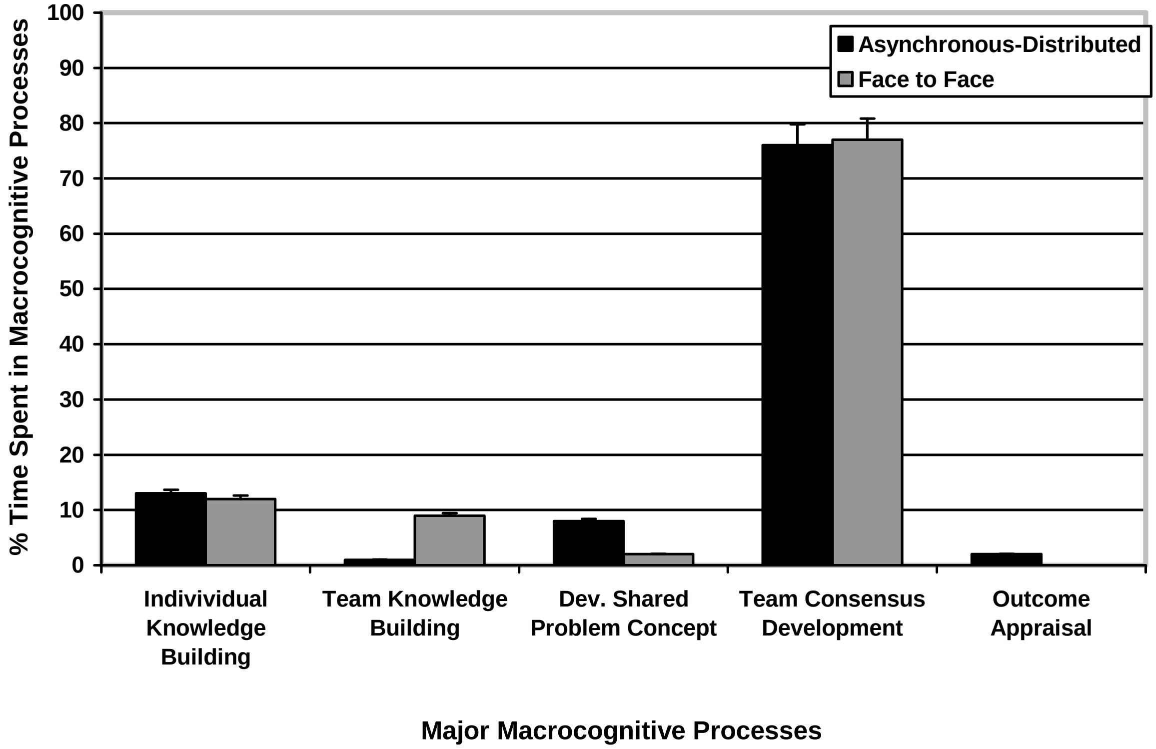

Figure 4: Percentage of Time Spent in Major Macrocognitive Processes by Collaboration Mode

During Knowledge Construction, Individual Knowledge Building, F=54.23, $p < 0.001$, Team Knowledge Building, F=58.47, $p < 0.001$; Developing Shared Problem Conceptualization, F=21.75, $p < 0.001$; and Team Consensus Development, F=68.56, $p < 0.001$, were found to occur a significant percentage of the time. During Collaborative Team Problem Solving, all five macrocognitive processes were significant: Individual Knowledge Building, F=32.51, $p < 0.001$; Team Knowledge Building, F=20.74, $p < 0.001$; Developing Shared Problem Conceptualization, F=17.52, $p < 0.001$; Team Consensus Development, F=785.17, $p < 0.001$; and Outcome Appraisal, F=4.10, $p < 0.05$. During Team Consensus, Team Consensus Development, F=18.45, $p < 0.001$, and Outcome Appraisal, F=4.04, $p < 0.05$, were both significant. Finally, during Outcome, Evaluation, and Revision only Team Consensus Development, F=9.69, $p < 0.01$, was significant. These results are summarized in figure 5.

	Team Collaboration Stages			
Macrocognitive Major Processes	Knowledge Construction	Team Problem Solving	Team Consensus	Outcome, Evaluation, and Revision
Individual Knowledge	**X**	**X**		

Building				
Team Knowledge Building	X	X		
Developing Shared Problem Conceptualization	X	X		
Team Consensus Development	X	X	X	X
Outcome Appraisal		X	X	

Figure 5: Taxonomy of Macrocognitive Major Processes and the Team Collaboration Stages

The univariate results for this analysis also produced some significant differences. During the Knowledge Construction stage, the face-to-face teams spent significantly more time in the Team Knowledge Building process than the asynchronous-distributed teams, $F=39.59$, $p < 0.001$. During the Collaborative Team Problem Solving stage, the face-to-face teams again spent significantly more time in the Team Knowledge Building process than the asynchronous-distributed teams, $F=7.47$, $p < 0.01$. However, during both the Knowledge Construction, $F=8.24$, $p < 0.01$, and Collaborative Team Problem Solving stages, $F=6.44$, $p < 0.05$, asynchronous-distributed teams spent significantly more time in the Developing Shared Problem Conceptualization process than the face-to-face teams. There were no other significant differences.

THE MACROCOGNITIVE SUBPROCESSES

The interrater reliability between the two raters based on their coding of the macrocognitive subprocesses was calculated. The interrater reliability was 0.71. A 2x2 ANOVA was used to analyze the percentage of total time spent in each of the macrocognitive subprocesses collaboration modes and the level of knowledge uncertainty. There was a significant difference between the two collaboration modes, $F=7.03$, $p < 0.01$. There was no significant difference for knowledge uncertainty, $F=1.10$, $p=0.45$. The interaction was not significant, $F=1.29$, $p=0.35$. The following subprocesses were significant: Iterative Information Collection, $F=44.47$, $p < 0.001$; Individual Task Knowledge Development, $F=186.87$, $p < 0.001$; Individual Mental Model Development, $F=28.67$, $p < 0.001$; Sharing Unique Knowledge, $F=6.68$, $p < 0.05$; Knowledge Interoperability, $F=141.96$, $p < 0.001$; Visualization and Representation of Meaning, $F=32.95$, $p < 0.001$; Knowledge Sharing, $F=66.46$, $p < 0.001$; Knowledge Transfer, $F=31.35$, $p < 0.001$; Team Shared Understanding, $F=13.63$, $p < 0.001$; Critical Thinking, $F=8.42$, $p < 0.01$; Solution Option Generation, $F=36.87$, $p < 0.001$; and Feedback Interpretation, $F=7.67$, $p < 0.01$ (see figure 6).

There were a number of significant ANOVA univariate results for each of the subprocesses (see figure 6). For Individual Task Knowledge Development, there was a significant difference depending on the collaboration mode, $F=17.32$, $p < 0.001$. Teams in the asynchronous-distributed condition spent more time in the Individual Task Knowledge Development subprocess that teams in the face-to-face condition. For Knowledge Interoperability, face-to-face teams spent more time than asynchronous-distributed teams, $F=52.16$, $p < 0.001$. There was a significant difference depending on the collaboration mode for Visualization and Representation of Meaning, $F=18.62$, $p < 0.001$. Face-to-face teams spent more time in this subprocess than teams in the asynchronous-distributed condition. For the subprocess of Solution Option Generation (see figure 7), asynchronous-distributed teams spent more time than face-to-face teams, $F=15.11$, $p < 0.001$. Teams in the static knowledge condition spent more time in the subprocess of Solution Option Generation than teams in the dynamic knowledge condition, $F=6.50$, $p < 0.05$. The interaction between knowledge uncertainty condition and the two collaboration modes was also significant, $F=5.89$, $p < 0.05$.

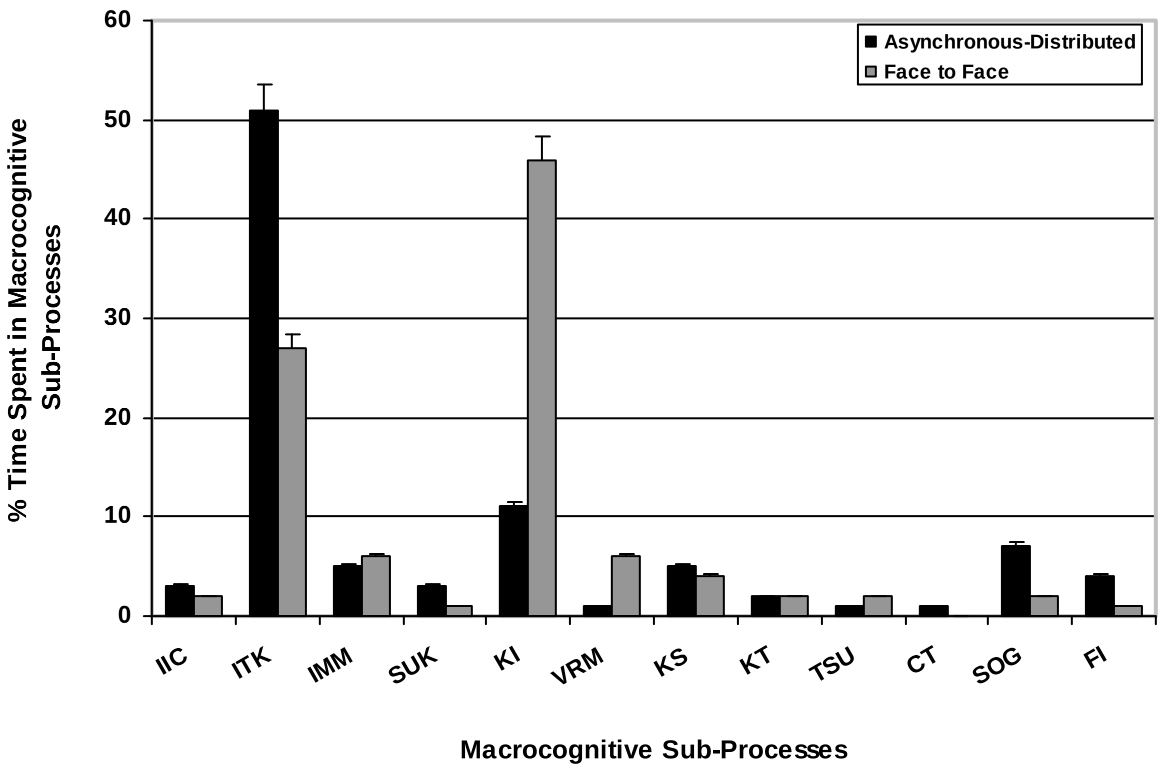

Figure 6: Percentage of Time Spent in Macrocognitive Subprocesses by Collaboration Mode

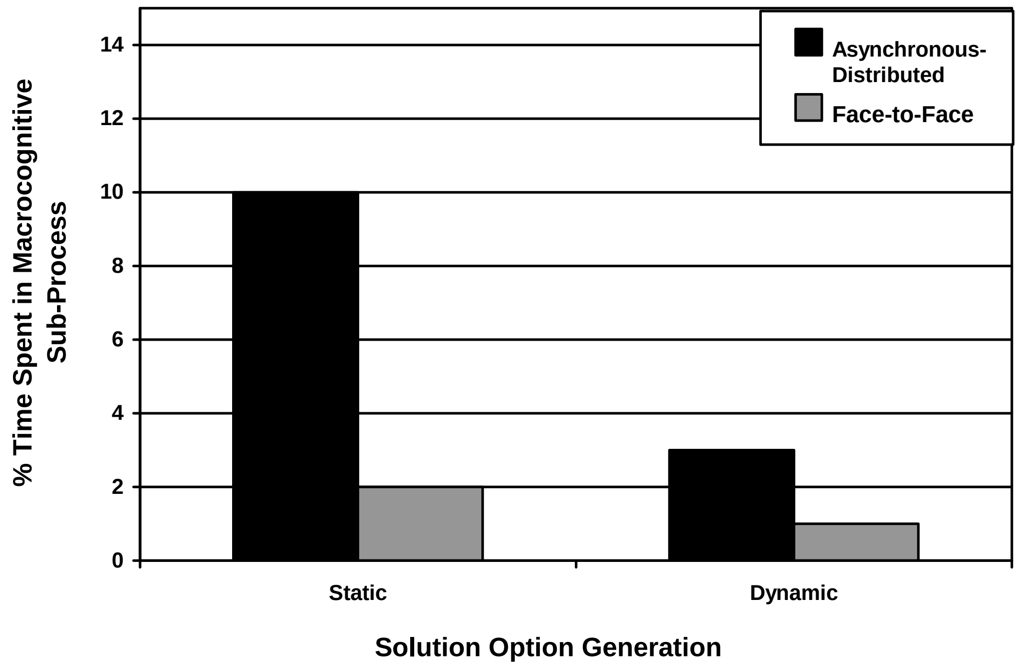

Figure 7: Percentage of Time Spent in Solution Option Generation across Two Independent Variables

As for the three secondary measures which were calculated based on the other macrocognitive subprocesses (see appendix K), these were analyzed based on the mean percentage of the total number of utterances. A 2x2 ANOVA was performed for these three dependent variables across knowledge uncertainty and collaboration mode. Face-to-face teams spend significantly more time engaged in the subprocess of Building Common Ground than asynchronous-distributed teams, $F=21.58$, $p < 0.001$. Asynchronous-distributed teams spent significantly more time in the Storyboarding subprocess than face-to-face teams, $F=19.93$, $p < 0.001$. There were no other significant differences. The significant results for the secondary measures are shown in figure 8.

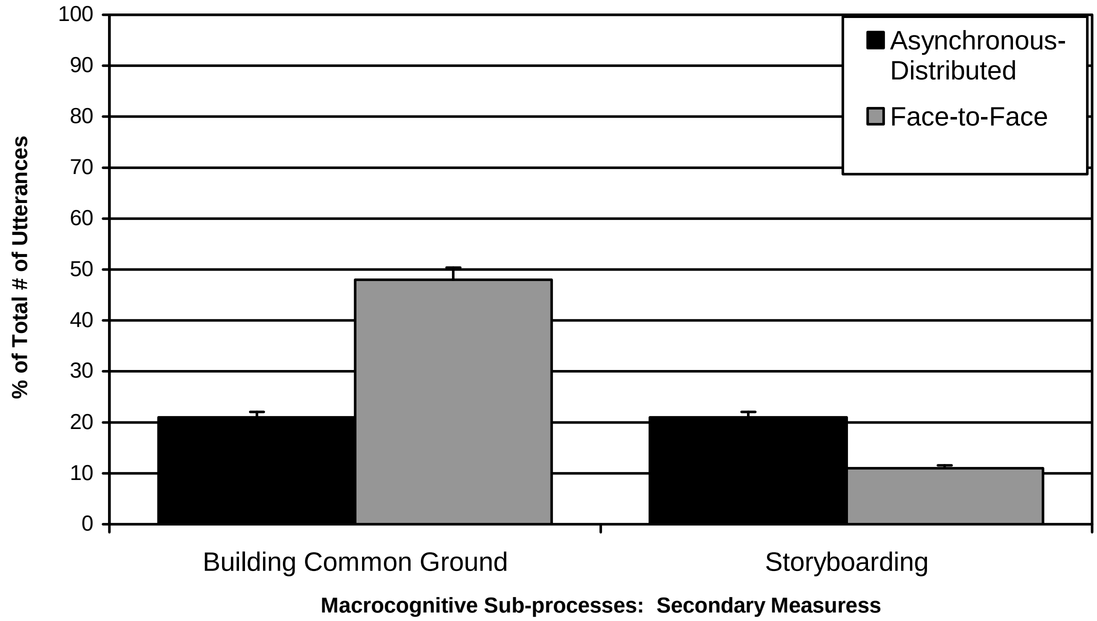

Figure 8: Three Macrocognitive Subprocesses across Collaboration Modes

The data were then transformed to examine how the macrocognitive subprocesses were nested within each of the major processes. For this analysis, only the subprocesses that were already found to be significant overall were included (see figure 6). A 2x2 ANOVA was then used to analyze the percentage of total time spent in each of the macrocognitive subprocesses that were found to be significant within each of the five major processes across collaboration modes and the level of knowledge uncertainty. There was a significant difference found for collaboration mode, $F=359.98$, $p < 0.05$. There was no significant main effect for knowledge uncertainty, $F=79.52$, $p=0.09$. The interaction between them was also not significant, $F=200.85$, $p=0.06$. During the Individual Knowledge Building major process, the following subprocesses were significant: Iterative Information Collection, $F=6.24$, $p < 0.05$; Individual Task Knowledge Development, $F=65.27$, $p < 0.001$; Individual Mental Model Development, $F=4.12$, $p < 0.05$; Sharing Unique Knowledge, $F=5.81$, $p < 0.05$; Knowledge Interoperability, $F=23.24$, $p < 0.001$; Visualization and Representation of Meaning, $F=9.88$, $p < 0.01$; Knowledge Sharing, $F=40.82$, $p < 0.001$; Knowledge Transfer, $F=6.15$, $p < 0.05$; Team Shared Understanding, $F=4.68$, $p < 0.05$; Building Common Ground, $F=28.86$, $p < 0.001$; and Storyboarding, $F=17.05$, $p < 0.001$. Within the macrocognitive major process Team Knowledge Building, the following subprocesses were found to be significant: Iterative Information Collection, $F=5.12$, $p < 0.05$; Individual Task Knowledge Development, $F=52.79$, $p < 0.001$; Individual Mental Model Development, $F=14.51$, $p < 0.001$; Knowledge Interoperability, $F=21.62$, $p < 0.001$; Visualization and Representation of Meaning, $F=16.03$, $p < 0.001$; Knowledge Sharing, $F=11.79$, $p < 0.01$; Team Shared Understanding, $F=11.58$, $p < 0.01$; Building Common Ground, $F=25.73$, $p < 0.001$; and Storyboarding, $F=46.39$, $p < 0.001$. During the Developing Shared Problem Conceptualization macrocognitive major process, the following subprocesses were significant: Iterative Information

Collection, F=4.84, p < 0.05; Individual Task Knowledge Development, F=39.87, p < 0.001; Knowledge Interoperability, F=6.43, p < 0.05; Knowledge Sharing, F=4.10, p < 0.05; Building Common Ground, F=7.92, p < 0.01; and Storyboarding, F=9.20, p < 0.01. Within the Team Consensus Development macrocognitive major process, the following subprocesses were significant: Iterative Information Collection, F=51.19, p < 0.001; Individual Task Knowledge Development, F=50.72, p < 0.001; Individual Mental Model Development, F=10.83, p < 0.01; Sharing Unique Knowledge, F=5.47, p < 0.05; Knowledge Interoperability, F=77.82, p < 0.001; Visualization and Representation of Meaning, F=19.28, p < 0.001; Knowledge Sharing, F=20.24, p < 0.001; Knowledge Transfer, F=21.04, p < 0.001; Team Shared Understanding, F=6.49, p < 0.05; Critical Thinking, F=4.78, p < 0.05; Solution Option Generation, F=29.93, p < 0.001; Feedback Interpretation, F=5.02, p < 0.05; Building Common Ground, F=127.92, p < 0.001; and Storyboarding, F=180.18, p < 0.001. Finally, within the Outcome Appraisal macrocognitive major process, only two subprocesses were found to be significant: Individual Task Knowledge Development, F=4.30, p < 0.05, and Building Common Ground, F=4.24, p < 0.05. These results are summarized in figure 9.

	Macrocognitive Major Processes				
Macrocognitive Subprocesses	Individual Knowledge Building	Team Knowledge Building	Developing Shared Problem Conceptualization	Team Consensus Development	Outcome Appraisal
Iterative Information Collection	X	X	X	X	
Individual Task Knowledge Development	X	X	X	X	X
Individual Mental Model Development	X	X		X	
Sharing Unique Knowledge	X			X	
Knowledge Interoperability	X	X	X	X	
Visualization and Representation of Meaning	X	X		X	
Knowledge Sharing	X	X	X	X	
Knowledge Transfer	X			X	
Team Shared Understanding	X	X		X	
Critical Thinking				X	
Solution Option Generation				X	
Feedback Interpretation				X	
Building Common Ground	X	X	X	X	X
Storyboarding	X	X	X	X	

Figure 9: Taxonomy of Macrocognitive Major Processes and Subprocesses

Regarding the univariate results for this analysis, there were a number of significant findings. Within Individual Knowledge Building, there was a significant difference across collaboration modes for Knowledge Interoperability, F=15.69, p < 0.001. Face-to-face teams spent more time in the Knowledge Interoperability subprocess during the macrocognitive major process of Individual Knowledge Building than asynchronous-distributed teams. Face-to-face teams spent more time in Visualization and Representation of Meaning than asynchronous-distributed teams while engaging in Individual Knowledge Building, F=9.46, p < 0.01. Face-to-face teams also spent more time engaged in Building Common Ground during Individual

Knowledge Building than asynchronous-distributed teams, F=11.66, $p < 0.01$. Asynchronous-distributed teams, however, spent more time engaged in Knowledge Sharing during Individual Knowledge Building than face-to-face teams, F=8.32, $p < 0.01$. There were no significant differences across knowledge uncertainty during Individual Knowledge Building.

For the macrocognitive major process of Team Knowledge Building there were significant differences for the univariate results as well. For Team Knowledge Building, there was a significant difference across collaboration mode for Individual Task Knowledge Development, F=21.80, $p < 0.001$. While engaging in Team Knowledge Building, face-to-face teams spent more time in the subprocess of Individual Task Knowledge Development than asynchronous-distributed teams. Within Team Knowledge Building, face-to-face teams spent more time engaged in Individual Mental Model Development than asynchronous-distributed teams, F=14.51, $p < 0.001$. While teams were engaged in Team Knowledge Building, face-to-face teams also spent more time than asynchronous-distributed teams engaged in Knowledge Interoperability, F=18.30, $p < 0.001$. For Team Knowledge Building, there was a significant difference for Visualization and Representation of Meaning across collaboration mode, F=16.03, $p < 0.001$. Within Team Knowledge Building, face-to-face teams spent more time engaged in Visualization and Representation of Meaning than asynchronous-distributed teams. Face-to-face teams also spent more time in Knowledge Sharing than asynchronous-distributed teams during Team Knowledge Building, F=11.79, $p < 0.01$, and in Building Common Ground, F=9,63, $p < 0.01$. During asynchronous-distributed teams' collaboration, more time was spent during Team Knowledge Building in the subprocess of Storyboarding, F=37.95, $p < 0.001$. Finally, during Team Knowledge Building, there was a significant difference across collaboration mode for Team Shared Understanding, F=11.57, $p < 0.01$. Face-to-face teams spent more time in Team Shared Understanding than asynchronous-distributed teams. During Team Knowledge Building, no significant differences were found across knowledge uncertainty.

Within Developing Shared Problem Conceptualization, there were only two significant differences found across collaboration mode. During Developing Shared Problem Conceptualization, asynchronous-distributed teams spent more time than face-to-face teams engaged in Individual Task Knowledge Development, F=18.93, $p < 0.001$, and in Storyboarding, F=6.05, $p < 0.05$. No significant differences were found across knowledge uncertainty for the macrocognitive major process of Developing Shared Problem Conceptualization.

During the macrocognitive major process of Team Consensus Development, there were also a number of significant differences. Within Team Consensus Development, there was a significant difference across collaboration mode for Iterative Information Collection, F=4.38, $p < 0.05$. Asynchronous-distributed teams spent more time in Iterative Information Collection than face-to-face teams. During Team Consensus Development, asynchronous-distributed teams spent more time than face-to-face teams engaged in Individual Task Knowledge Development, F=16.57, $p < 0.001$, and in Storyboarding, F=15.24, $p < 0.001$. Within the Team Consensus Development major process, face-to-face teams spent more time than asynchronous-distributed teams engaged in Knowledge Interoperability, F=13.08, $p < 0.01$, and in Building Common Ground, F=20.29, $p < 0.001$. Face-to-face teams also spent more time than asynchronous-distributed teams engaged in Visualization and Representation of Meaning during Team Consensus Development, $F=6.30$, $p < 0.05$. Within Team Consensus Development, there was a significant difference for Solution Option Generation across both collaboration mode, $F=15.17$, $p < 0.001$, and knowledge uncertainty, $F=8.78$, $p < 0.01$, and the interaction was significant, $F=6.43$, $p < 0.05$. During Team Consensus Development, asynchronous-distributed teams spent more time engaged in Solution Option Generation than face-to-face teams, and static knowledge teams spent more time in Solution Option Generation than dynamic teams. Asynchronous-distributed teams spent more time engaged in Storyboarding than face-to-face teams during Team Consensus Development, $F=15.24$, $p < 0.001$.

Finally, there were no significant differences found across collaboration mode or knowledge uncertainty for any of the subprocesses within the macrocognitive major process of Outcome Appraisal. There were also no significant interactions found for the subprocesses during Outcome Appraisal.

A NEW TAXONOMY

The results summarized in figures 5 and 9 combined still do not address the issue of which of the macrocognitive subprocesses support each of the team collaboration stages during problem solving. In order to complete a new taxonomy based on the revised definitions (Letsky, et al., 2007), and the re-analyses presented in this report, the data were transformed to examine which of the macrocognitive subprocesses were engaged in a significant percent of time in each of the team collaboration stages. A 2x2 ANOVA was then used to analyze the percentage of total time spent in each of the macrocognitive subprocesses within each of the team collaboration stages across collaboration modes and the level of knowledge uncertainty. For this analysis, only the subprocesses that were already found to be significant overall were included (see figure 6). Overall, there was no significant difference between the two collaboration modes, $F=9.10$, $p=0.26$, or the knowledge uncertainty conditions, $F=0.63$, $p=0.78$. The interaction was also not significant, $F=1.48$, $p=0.58$. The following subprocesses were significant during the Knowledge Construction team collaboration stage: Iterative Information Collection, $F=9.97$, $p < 0.01$; Individual Task Knowledge Development, $F=135.19$, $p < 0.001$; Individual Mental Model Development, $F=10.31$, $p < 0.01$; Sharing Unique Knowledge, $F=5.033$, $p < 0.05$; Knowledge Interoperability, $F=67.34$, $p < 0.001$; Visualization and Representation of Meaning, $F=20.80$, $p < 0.001$; Knowledge Sharing, $F=32.66$, $p < 0.001$; Knowledge Transfer, $F=9.35$, $p < 0.01$; Team Shared Understanding, $F=12.81$, $p < 0.01$; Building Common Ground, $F=102.16$, $p < 0.001$; and Storyboarding, $F=40.20$, $p < 0.001$. The following subprocesses were significant during the Collaborative Team Problem Solving stage: Iterative Information Collection, $F=36.84$, $p < 0.001$; Individual Task Knowledge Development, $F=132.38$, $p < 0.001$; Individual Mental Model Development, $F=44.49$, $p < 0.001$; Sharing Unique Knowledge, $F=7.11$, $p < 0.05$; Knowledge Interoperability, $F=127.26$, $p < 0.001$; Visualization and Representation of Meaning, $F=23.97$, $p < 0.001$; Knowledge Sharing, $F=35.96$, $p < 0.001$; Knowledge Transfer, $F=30.21$, $p < 0.001$; Team Shared Understanding, $F=9,50$, $p < 0.01$; Critical Thinking, $F=7.84$, $p < 0.01$; Solution Option Generation, $F=31.68$, $p < 0.001$; Feedback Interpretation, $F=7.14$, $p < 0.05$; Building Common Ground, $F=133.09$, $p < 0.001$; and Storyboarding, $F=148.76$, $p < 0.001$. The following subprocesses were significant during the Team Consensus stage: Individual Task Knowledge Development, F=4.05, $p < 0.05$; Knowledge Interoperability, F=26.26, $p < 0.001$; Visualization and Representation of Meaning, F=4.40, $p < 0.05$; Building Common Ground, F=20.02, $p < 01$; and Storyboarding, F=6.00, $p < 0.05$. The following subprocesses were significant during the Outcome, Evaluation, and Revision stage: Knowledge Interoperability, F=4.08, $p < 0.05$; Visualization and Representation of Meaning, F=4.05, $p < 0.05$; and Building Common Ground, F=4.91, $p < 0.05$.

There were also some significant findings within the univariate results for this analysis. During Knowledge Construction, there was a significant difference across collaboration modes for Knowledge Interoperability, F=50.55, $p < 0.001$. Face-to-face teams spent more time in the Knowledge Interoperability subprocess within the team collaboration stage of Knowledge Construction than asynchronous-distributed teams. Face-to-face teams also spent more time in Visualization and Representation of Meaning than asynchronous-distributed teams during the Knowledge Construction stage, F=20.77, $p < 0.001$. Within Knowledge Construction, face-to-face teams spent more time than asynchronous-distributed teams engaged in both Knowledge Transfer, F=8.25, $p < 0.01$, and Team Shared Understanding, F=12.81, $p < 0.01$. During the Collaborative Team Problem Solving stage, significant differences were found for the following subprocesses: Individual Task Knowledge Development, F=20.26, $p < 0.001$; Individual Mental Model Development, F=6.48, $p < 0.05$; Knowledge Interoperability, F=42.88, $p < 0.001$; Visualization and Representation of Meaning, F=12.75, $p < 0.01$; Solution Option Generation, F=11.56, $p < 0.01$; Building Common Ground, F=20.37, $p < 0.001$; and Storyboarding, F=11.90, $p < 0.01$. During Collaborative Team Problem Solving, face-to-face teams spent more time engaged in Individual Mental Model Development, Knowledge Interoperability, Visualization and Representation of Meaning, and Building Common Ground than asynchronous-distributed teams. However, asynchronous-distributed teams spent more time engaged in Individual Task Knowledge Development, Solution Option Generation, and Storyboarding, than face-to-face teams. During Collaborative Team Problem Solving, there was also a significant difference found between the uncertainty conditions for the subprocess of Solution Option Generation, F=6.45, $p < 0.05$. Teams in the static knowledge condition spent more time engaged in Solution Option Generation than teams in the dynamic knowledge condition. The interaction across collaboration mode and knowledge uncertainty for Solution Option Generation was also significant, F=6.51, $p < 0.05$. During Team Consensus, significant differences were only found for two subprocesses. Face-to-face teams spent more time engaged in both Knowledge Interoperability, F=13.53, $p < 0.001$, and Visualization and Representation of Meaning, F=4.40, $p < 0.05$, than asynchronous-distributed teams. During Outcome, Evaluation, and Revision, there were no significant differences found for any of the subprocesses.

Figure 5 shows how the macrocognitive major processes supported each of the team collaboration stages, while figure 9 shows how the macrocognitive subprocesses were nested within the macrocognitive major processes. Figure 10 combines these results with those just reported related to how the subprocesses also support the team collaboration stages to form an empirically based revised taxonomy using the new definitions (Letsky, et al., 2007).

	Team Collaboration Stages			
Macrocognitive Major Processes (shaded) and Macrocognitive Subprocesses	Knowledge Construction	Team Problem Solving	Team Consensus	Outcome, Evaluation, and Revision
Individual Knowledge Building	X	X		
Iterative Information Collection	X	X		
Individual Task Knowledge Development	X	X		
Individual Mental Model Development	X	X		
Sharing Unique Knowledge	X	X		
Knowledge Interoperability	X	X		
Visualization and Representation of Meaning	X	X		
Knowledge Sharing	X	X		
Knowledge Transfer	X	X		
Team Shared Understanding	X	X		
Building Common Ground	X	X		
Storyboarding	X	X		
Team Knowledge Building	X	X		
Iterative Information Collection	X	X		
Individual Task Knowledge Development	X	X		
Individual Mental Model Development	X	X		
Knowledge Interoperability	X	X		
Visualization and Representation of Meaning	X	X		
Knowledge Sharing	X	X		
Team Shared Understanding	X	X		
Building Common Ground	X	X		
Storyboarding	X	X		
Developing Shared Problem Conceptualization	X	X		
Iterative Information Collection	X	X		
Individual Task Knowledge Development	X	X		
Knowledge Interoperability	X	X		
Knowledge Sharing	X	X		
Building Common Ground	X	X		
Storyboarding	X	X		
Team Consensus Development	X	X	X	X
Iterative Information Collection	X	X		
Individual Task Knowledge Development	X	X	X	
Individual Mental Model Development	X	X		
Sharing Unique Knowledge	X	X		
Knowledge Interoperability	X	X	X	X
Visualization and Representation of Meaning	X	X	X	X
Knowledge Sharing	X	X		
Knowledge Transfer	X	X		
Team Shared Understanding	X	X		
Critical Thinking		X		
Solution Option Generation		X		
Feedback Interpretation		X		
Building Common Ground	X	X	X	X
Storyboarding	X	X	X	
Outcome Appraisal		X	X	
Individual Task Knowledge Development		X	X	
Building Common Ground		X	X	

Figure 10: New Taxonomy of the Collaboration Stages, Macrocognitive Major Processes, and Subprocesses

HOW TEAMS TRANSITION BETWEEN THE STAGES AND MAJOR PROCESSES

Regarding the dynamic nature of the team collaboration stages and macrocognitive major processes, figure 11 was taken from Warner and Wroblewski's (2005; 2006) presentations of the data from the original NEO experiment (Warner, Letsky, and Cowen, 2005). It depicts the probabilities of the transitions between the team collaboration stages across the two collaboration conditions.

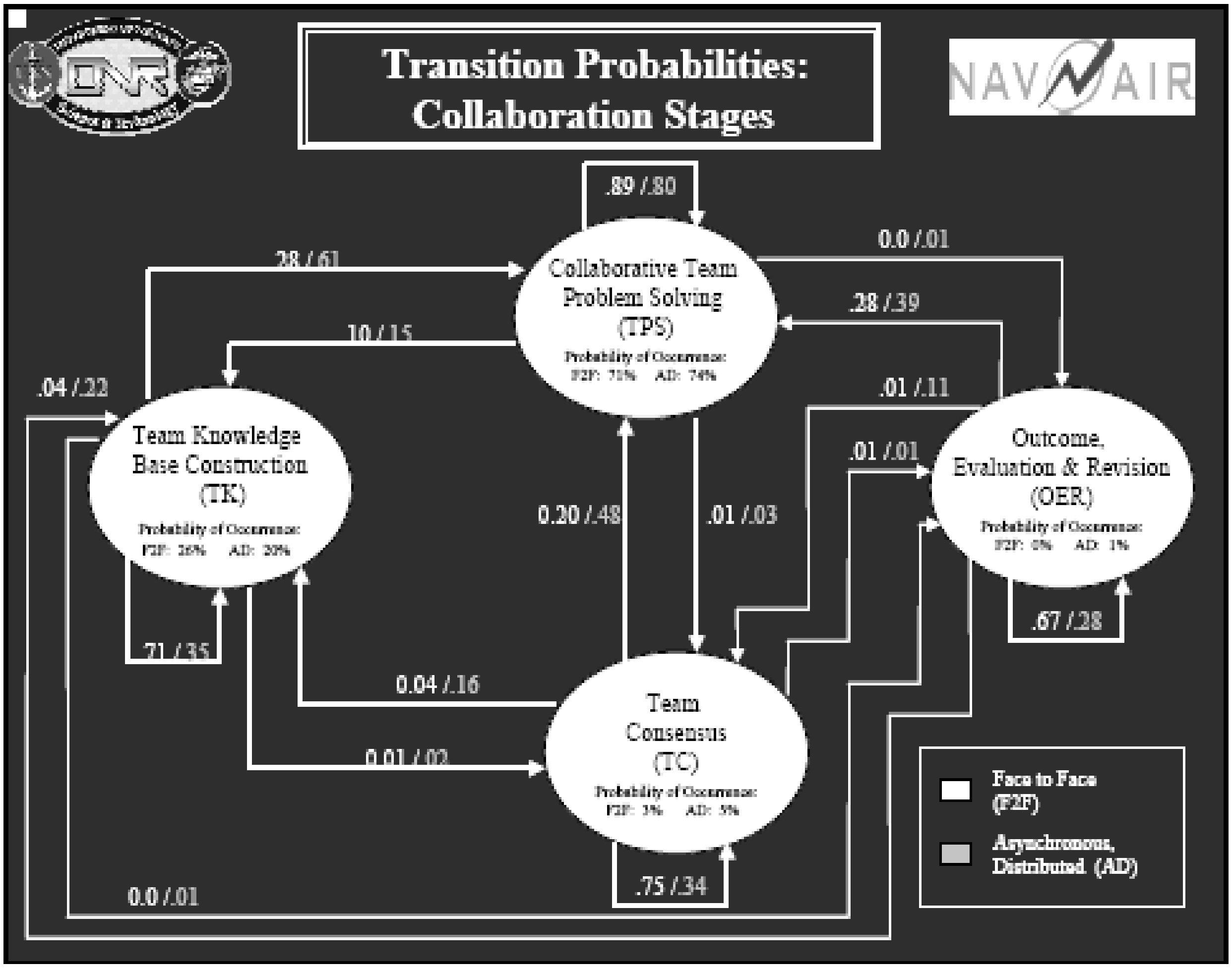

Figure 11: Transition Probabilities for the Team Collaboration Stages

In order to analyze the transition probabilities between the macrocognitive major processes, all the transitions between two different macrocognitive major processes were counted, totaled, and converted into probabilities. A 2x2 ANOVA was used to analyze these transition probabilities across collaboration mode and knowledge uncertainty. There was a significant main effect for collaboration mode, $F=7.22$, $p < 0.001$; however, there was no significant difference across knowledge uncertainty, $F=1.81$, $p = 0.16$. The following transition probabilities between the macrocognitive major processes were significant: Individual Knowledge Building → Team

Knowledge Building, $F=22.16$, $p < 0.001$; Individual Knowledge Building → Developing Shared Problem Conceptualization, $F=19.45$, $p < 0.001$; Individual Knowledge Building → Team Consensus Development, $F=588.42$, $p < 0.001$; Team Knowledge Building → Individual Knowledge Building, $F= 19.16$, $p < 0.001$; Team Knowledge Building → Developing Shared Problem Conceptualization, $F=4.31$, $p < 0.05$; Team Knowledge Building → Team Consensus Development, $F=117.59$, $p < 0.001$; Developing Shared Problem Conceptualization → Individual Knowledge Building, $F=24.56$, $p < 0.001$; Developing Shared Problem Conceptualization → Team Knowledge Building, $F=5.97$, $p < 0.05$; Developing Shared Problem Conceptualization → Team Consensus Development, $F=267.94$, $p < 0.001$; Team Consensus Development → Individual Knowledge Building, $F=437.09$, $p < 0.001$; Team Consensus Development → Team Knowledge Building, $F=111.01$, $p < 0.001$; Team Consensus Development → Developing Shared Problem Conceptualization, $F=145.04$, $p < 0.001$; and Team Consensus Development → Outcome Appraisal, $F=9.91$, $p < 0.01$.

There were some significant univariate differences across collaboration mode (see figure 12); however, there were no differences found across knowledge uncertainty. Face-to-face teams had a higher probability than asynchronous-distributed teams of engaging in the following macrocognitive major process transitions: Individual Knowledge Building → Team Knowledge Building, $F=10.68$, $p < 0.01$; Team Knowledge Building → Individual Knowledge Building, $F=9.20$, $p < 0.01$; Team Knowledge Building → Developing Shared Problem Conceptualization, $F=4.31$, $p < 0.05$; Team Knowledge Building → Team Consensus Development, $F= 62.04$, $p < 0.001$; and Team Consensus Development → Team Knowledge Building, $F=60.94$, $p < 0.001$. Asynchronous-distributed teams had a higher probability than face-to-face teams of engaging in the following transitions: Individual Knowledge Building → Developing Shared Problem Conceptualization, $F=7.77$, $p < 0.01$; Developing Shared Problem Conceptualization → Individual Knowledge Building, $F=6.09$, $p < 0.05$; Developing Shared Problem Conceptualization → Team Consensus Development, $F=47.47$, $p < 0.001$; Team Consensus Development → Developing Shared Problem Conceptualization, $F=23.27$, $p < 0.001$; and Team Consensus Development → Outcome Appraisal, $F=4.61$, $p < 0.05$.

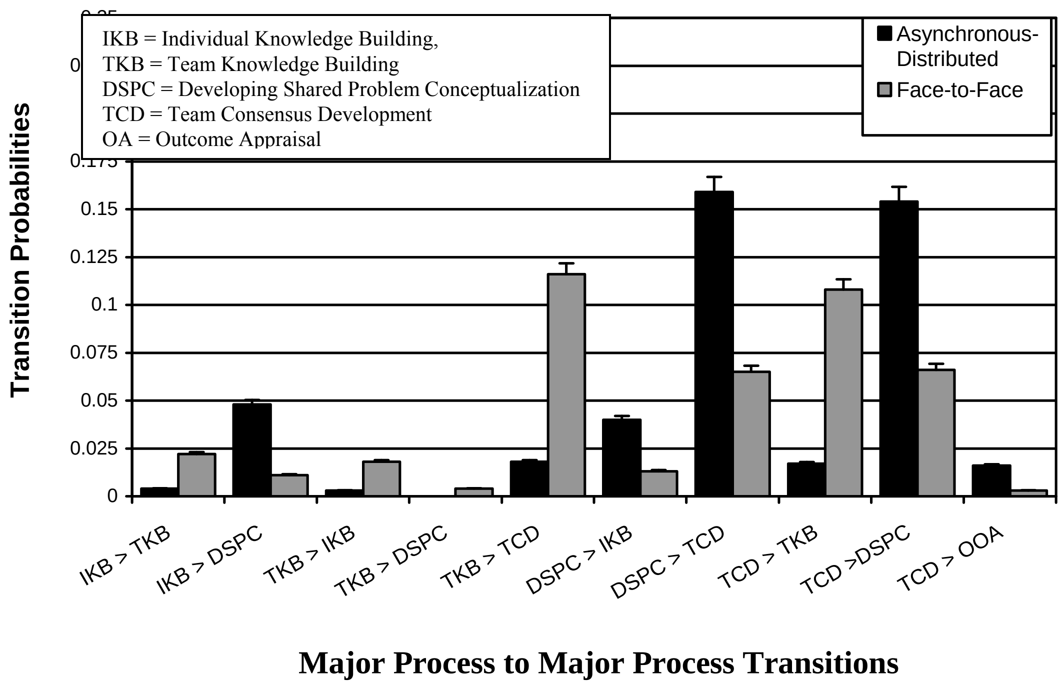

Figure 12: Probabilities of Transitions between the Major Macrocognitive Processes

DISCUSSION

The goal of the current re-analyses was to examine the consistency and contributions of the team collaboration stages and macrocognitive processes proposed by Letsky and colleagues (2007) in order to facilitate a better understanding of the team collaboration process. The results of the re-analyses support the contribution of the four collaboration stages during the process of team collaboration while solving the NEO scenario-based problem. The contribution of all five major macrocognitive processes during team collaboration was also significant. The results of the present re-analyses provided support for some of the macrocognitive subprocesses in terms of both their consistency and contribution. In addition, there were significant differences, depending on the collaboration mode used by the teams, in terms of the collaboration stages, macrocognitive major processes, and macrocognitive subprocesses. In the following sections, the specific results regarding the team collaboration stages, macrocognitive major, and subprocesses will be discussed. The subsequent sections will discuss how teams transition between the stages and major processes, the consistency and contribution of the stages and processes, the new taxonomy, and the evolution of the team collaboration model. Finally, areas for future research will be discussed.

THE TEAM COLLABORATION STAGES

The results from the original analyses of the NEO transcripts and experimental data (Warner, Letsky, and Cowen, 2005) regarding the team collaboration stages were that, overall, a significant amount of time was spent in each of the four team collaboration stages. As was mentioned earlier, this result was significant for the NEO scenario, but not for the murder mystery scenario (Warner, Letsky, and Cowen, 2005), during which teams did not spend a significant amount of time engaged in the Outcome, Evaluation, and Revision stage. The researchers attributed this finding to the types of solutions required to solve the two different scenarios. The murder mystery scenario had a fixed solution, whereas researchers created the NEO scenario (Warner, Wroblewski, and Shuck, 2004) to have numerous possible solutions that varied in terms of how optimal they were (compared to those planned by experts) and this seemed to lead to teams spending a significant amount of time in the Outcome, Evaluation, and Revision stage. Warner and colleagues (2005) concluded that, based on their data, the team collaboration stages seem to be dependent upon the type of task. Hutchins (2008) also found support for the notion that the team collaboration stages are domain dependent.

There were significant differences across collaboration mode for only two of the team collaboration stages. The face-to-face teams spent more time in Knowledge Construction than the asynchronous-distributed teams. However, the asynchronous-distributed teams spent more time in the Collaborative Team Problem Solving stage than the face-to-face teams. This means that, based on the definitions of the stages (see Letsky, et al., 2007), during face-to-face collaboration teams spent more time reading, clarifying information and understanding the problem than the asynchronous-distributed teams. Whereas, the asynchronous-distributed teams spent more time communicating data and knowledge to develop solutions to the problem than face-to-face teams. When communicating in a face-to-face situation, team members seemed to be more likely to overtly convey their need to read information and share their thoughts while trying to understand the problem (e.g., through speech, which is then coded during communication analyses by raters) than when they are communicating in an asynchronous-distributed manner. Time spent reading information to oneself or trying to understand the problem without any overt communication (e.g., speaking or typing) was not measured in this study since only the overt communication was coded during the communication analysis for this experiment. The second difference across collaboration mode was that asynchronous-distributed teams seemed to spend more time engaged in the Collaborative Team Problem Solving stage, in other words, communicating (e.g., through typing messages back and forth) data and knowledge to each other, than face-to-face teams. This may, in part, be because face-to-face teams were better able to quickly communicate and assess the need to further discuss such information through gestures, facial expressions, or even using words such as “this” or “that” in reference to people, places, or things that may be more easily confused when communicating in an asynchronous-distributed manner. Both of these differences across collaboration mode need to be further examined in future research in order to be able to gain a better understanding of the nonverbal (e.g., gestures) and internalized components of the team collaboration process. This topic will be discussed further in the Future Research section of this paper.

THE MACROCOGNITIVE MAJOR PROCESSES

The present re-analyses were based on the most recent version of the taxonomy and definitions (Letsky, et al., 2007). The original team collaboration stages data from Warner, Letsky, and Cowen's study (2005) was used, but the re-analyses extended the original findings to include how the new macrocognitive major processes support these stages. The general breakdown of the team collaboration stages by the macrocognitive major processes is shown in figure 5.

Overall, there was a significant difference found across collaboration mode for the macrocognitive major processes as they supported the team collaboration stages. During the Knowledge Construction stage, two of the major processes differed in terms of the percentage of time spent based on the collaboration mode. During this stage, face-to-face teams spent significantly more time engaged in the process of Team Knowledge Building than asynchronous-distributed teams. However, asynchronous-distributed teams spent more time in the Developing Shared Problem Conceptualization process than face-to-face teams during the Knowledge Construction stage. During the Collaborative Team Problem Solving stage, there were also two major processes that were found to differ significantly across collaboration mode. During this stage, the face-to-face teams spent more time in the Team Knowledge Building process than the asynchronous-distributed teams. Asynchronous-distributed teams spent significantly more time engaged in Developing Shared Problem Conceptualization than the face-to-face teams.

These results correspond to the overall differences found between the macrocognitive major processes when they were analyzed independently of the team collaboration stages. Overall, face-to-face teams spent more time engaged in Team Knowledge Building than asynchronous-distributed teams. One possible explanation for this may relate to the definition that the researchers used to code the transcripts during communication analyses. Team Knowledge Building is described as occurring when *all* team members participate in clarifying information (e.g., answering a question) to build team knowledge (see Letsky, et al., 2007). While working in an asynchronous-distributed manner, it is possible that team members may not always type what they may be thinking while information is being clarified. For example, in a face-to-face conversation, one person may ask a question, a second person on the team may provide the answer, and the third person may follow with a statement of agreement (e.g., okay or uh-huh). Since all three people on the team were involved in this part of the conversation, it would be coded as Team Knowledge Building by the raters during communication analysis. However, in the asynchronous-distributed condition, the third person on the team may not bother typing "okay", but may be nodding (which would not be identified through the communication analyses), or simply may note the newly clarified information to him/herself. This would not be coded as Team Knowledge Building because only two out of three team members have typed anything that will be coded during the communication analyses. Future research that incorporates other measures of team members' behaviors during collaboration, (e.g., through eye-tracking and the monitoring of gestures) will facilitate a better understanding of this difference between communication patterns between face-to-face and asynchronous-distributed teams.

The second overall difference found between the macrocognitive major processes was that asynchronous-distributed teams spent more time engaged in Developing Shared Problem Conceptualization than face-to-face teams. Once again, face-to-face teams may have had an advantage over asynchronous-distributed teams that led to this finding. Developing Shared Problem Conceptualization involves team members sharing their understanding of problem goals, characteristics of the environment, and rules for operating the generation of quality problem solutions (see Letsky, et al., 2007). People who need to communicate from different locations may feel the need to spend a certain amount of time making sure that each person involved has come to the same understanding concerning the team's goals and rules or guidelines of the problem. Face-to-face teams may not need to spend as much time overtly making sure of this type of team-shared understanding since they are able to see whether or not each team member has finished reading something, has seen a particular map, or even if someone has a confused look on their face.

Gutwin and Greenberg (2004) discuss the importance of awareness during distributed collaboration, specifically an awareness of "what is going on" (Endsley, 1995 as cited in Gutwin and Greenberg, 2004). During the process of Developing Shared Problem Conceptualization, team members communicate about "what is going on" in terms of important guidelines, goals, and characteristics of the environment. Gutwin and Greenberg (2004) suggest that it is not only verbal communication that is important during team collaboration, but also:

> "team collaboration includes activities such as using environmental cues to establish a common ground of understanding, seeing who is around and what they are doing, monitoring the state of artifacts in a shared work setting, noticing other people's gestures and what they are referring to, and so on" (2004, p. 177).

In their chapter, the authors discuss the fact that distributed communication systems and tools often do not offer a lot of support regarding maintaining awareness, such as shared white-boards (Gutwin and Greenberg, 2004), which were not a part of the collaboration environment used for the NEO experiment (see Warner, Letsky, and Cowen, 2005). Thus, it is not surprising that, in order to compensate, teams in the asynchronous-distributed condition spent more time overtly communicating information to improve team awareness compared to face-to-face teams.

In terms of the other macrocognitive major processes, Individual Knowledge Building, Team Consensus Development, and Outcome Appraisal, no significant differences were found across collaboration mode overall or when examined in terms of the team collaboration stages they support. During both the face-to-face and asynchronous-distributed conditions, teams spent a significant amount of time in each of the macrocognitive major processes. There were no significant differences found across the static versus dynamic knowledge uncertainty conditions for any of the five major processes, and there were no significant interaction effects for the macrocognitive processes when analyzed individually, or in relation to the team collaboration stages.

THE MACROCOGNITIVE SUBPROCESSES

Overall, during collaboration on the NEO problem, the present re-analyses revealed that teams spent a significant percentage of their time engaged in fourteen of the macrocognitive subprocesses (see figure 9). The following subprocesses, however, were not significant: Team Pattern Recognition and Trend Analysis, Team Mental Model Development, Recognition of Expertise, Uncertainty Resolution, Intuitive Decision Making, Team Negotiation of Solution Alternatives, Replanning, and Mental Simulation.

In comparison to the original analyses performed using an earlier taxonomy and set of definitions (Warner, Letsky, and Cowen, 2005), there were several significant differences. Warner and colleagues (2005) found Team Pattern Recognition, Convergence of Mental Models (re-named Team Mental Model Development in the revised set of definitions, see Letsky, et al., 2007), and Team Negotiation of Solution Alternatives to be significant, however, this was not the case in the present re-analyses. There are several possible explanations for these results. The first possibility is that when the two new raters were coding the transcripts, one of the lines during a piece of the conversation was not interpreted to be closely enough related and was, therefore, labeled separately. Since, for each of these three subprocesses, the team as a whole needs to take part (see appendix K), a difference in the interpretation of one line may have lead to a different label of the other lines as well. Specifically, it may have led the raters to code the lines as a different subprocess that does not involve all team members (e.g., Individual Mental Model Development). Another possibility in regards to the difference in the results concerning the Team Negotiation of Solution Alternatives subprocess is that the addition of several new subprocesses in the new taxonomy led to different labeling by the two raters. In the new taxonomy, two of the new subprocesses were Feedback Interpretation and Replanning (see Letsky, et al., 2007). Team Negotiation of Solution Alternatives, Feedback Interpretation, and Replanning all have to do with discussing solution alternatives. In fact, in the present re-analyses, although Team Negotiation of Solution Alternatives was not significant, Feedback Interpretation was. Thus, it is possible that the inclusion of the two new subprocesses at least partially contributed to the different results. This may have been because there was overlap between the three subprocesses and that their definitions are not highly orthogonal, or because some parts of the transcript that were originally coded as Team Negotiation of Solution Alternatives now fit better under either the Feedback Interpretation or Replanning subprocesses.

Another difference found between the present re-analyses and the original analyses performed by Warner, Letsky, and Cowen (2005) was that several of the new subprocesses that were added into the revised taxonomy (see Letsky, et al., 2007) were significant. The following new subprocesses were significant: Feedback Interpretation (which was already discussed), Sharing Unique Knowledge, Knowledge Sharing, Knowledge Transfer, Critical Thinking, Building Common Ground, and Storyboarding. Thus, it appears that teams engaged in these new subprocesses often enough for them to be added into a new model of team collaboration.

Overall, there was a significant difference found across collaboration mode for a number of the macrocognitive subprocesses. Face-to-face teams spent more time than asynchronous-distributed teams engaged in the following subprocesses: Knowledge Interoperability, Visualization and Representation of Meaning, and Building Common Ground. During the asynchronous-distributed condition, however, teams spent more time engaged in the Individual Task Knowledge Development, Solution Option Generation, and Storyboarding subprocesses.

In order to discuss possible explanations for these differences across the two collaboration modes, each macrocognitive subprocess needs to be considered separately. First, one possible explanation for the greater percentage of time spent by face-to-face teams engaging in Knowledge Interoperability relates to the definition used during the raters' coding process. Knowledge Interoperability refers to when *all* team members are exchanging their knowledge of the problem situation in order to reach agreement in regards to a topic's meaning (see Letsky, et al., 2007). Similar to the explanation for the macrocognitive major process of Team Knowledge Building (which also requires all team members to participate), it may be that the lack of overt participation from one team member led the two raters to label this part of the conversation a different subprocess. This would have led to fewer lines being coded as Knowledge Interoperability for the asynchronous-distributed teams. Another possible explanation for the collaboration mode difference for the Knowledge Interoperability subprocess could be that teams working in a face-to-face manner simply spent more time engaged in the process of exchanging their knowledge of the problem situation while trying to come to a consensus about a topic's meaning than teams working from different locations. Future research that includes eye-tracking measures or that examines gestures may help to provide insight regarding differences in Knowledge Interoperability.

The description provided by Letsky and colleagues (2007) of the subprocess of Visualization and Representation of Meaning may help with a better understanding of the differences found across the two collaboration modes. Visualization of Meaning refers to when team members use visual aides, such as pictures or maps, to help transfer meaning to another team member. Representation of Meaning refers to when individual team members use methods such as note pads to sort information into groups. Since face-to-face teams each had the same maps and pictures in front of them during the experiment, it was easy for team members to refer others to these visual aides. In addition, the face-to-face teams could pass notes made on a pad. During the asynchronous-distributed teams' collaboration, team members may have spent time referring to these types of visual aides, however; they may not have typed anything to other team members about it. Therefore, it would not have ended up in the transcripts for raters to code. This is one highly plausible explanation for the finding that a significantly higher percentage of time was coded as Visualization and Representation of Meaning for the face-to-face teams when compared to the asynchronous-distributed teams. Warner, Letsky, and Cowen (2005) also found that face-to-face teams spent significantly more time engaged in Visualization and Representation of Meaning than asynchronous-distributed teams as well.

As for the face-to-face teams' spending more time than asynchronous-distributed teams engaged in Building Common Ground, the explanation may lie in how this secondary measure was calculated for this study (see appendix K). For the present re-analyses, the researchers created a composite Building Common Ground score that included the lines coded as

Recognition of Expertise, Team Pattern Recognition and Trend Analysis, Team Mental Model Development, Team Shared Understanding, Team Negotiation of Solution Alternatives, and Feedback Interpretation. With the exception of Recognition of Expertise, all of the other subprocesses listed above must include *all* three team members. Therefore, the lack of an overt response by only one team member in the asynchronous-distributed condition may have led to fewer lines of conversation being coded as one the above subprocesses, as was also likely the case with Knowledge Interoperability.

For the asynchronous-distributed teams, a larger percentage of time was spent engaged in the Individual Task Knowledge Development subprocess than during face-to-face team collaboration. This macrocognitive subprocess involves question asking and answering about data, information about the task, or planned actions (see appendix K). One possible reason for this finding is that the environment used by the three-member asynchronous-distributed teams could easily be used like a chat room on the internet or an Instant Messaging program. Therefore, this type of basic “Q and A” that fits into the Individual Task Knowledge Development subprocess was very well facilitated, and team members used it a great deal. A second possible explanation is that during face-to-face collaboration team members may have been more likely to add further insight or provide analysis in relation to the answer to a question in keeping with the natural flow of the conversation. This may have led raters to select other subprocess codes during communication analyses (e.g., Iterative Information Collection, Knowledge Interoperability, or Team Mental Model Development; see appendix K). Another possibility is since they were collaborating from different locations, asynchronous-distributed teams simply needed to spend additional time clarifying data or information about the task. This may be (at least) partially because face-to-face teams were better able to quickly assess their team members’ shared understanding of the data through nonverbal cues (e.g., facial expression or gestures). This was also offered as one explanation for a similar finding related to the Collaborative Team Problem Solving stage (discussed earlier). Finally, another possible explanation for the Individual Task Knowledge Development difference across collaboration mode is that asynchronous--distributed team members may have felt a greater need to clarify data and/or information, perhaps in an attempt to “bridge-the-gap” between themselves and the other team members.

Another macrocognitive subprocess for which there were significant differences across collaboration modes was Storyboarding. Asynchronous-distributed teams spent significantly more time engaged in the Storyboarding subprocess than face-to-face teams. The most plausible explanation for this is that the asynchronous-distributed environment that was used facilitated a “storyboarding”-like format by having team members create “cards” and post them so that other team members could read whatever was on them. This seems to have lead to asynchronous-distributed teams engaging in more Storyboarding than the face-to-face teams.

For the Solution Option Generation subprocess there was not only a significant difference found across collaboration modes, but across knowledge uncertainty conditions as well. Asynchronous-distributed teams spent more time engaged in the Solution Option Generation subprocess than teams in the face-to-face condition. Teams in the static knowledge condition spent more time in the Solution Option Generation subprocess than team in the dynamic knowledge condition. The interaction was also significant.

The fact that teams in the asynchronous-distributed condition spent more time engaged in Solution Option Generation may be due to the nature of the environment used for this condition. As was just discussed with the Storyboarding subprocess, the program used by the asynchronous-distributed teams was set up to have individual team members post electronic "cards" with typed information on them for other team members to see. Thus, it facilitated the brainstorming of ideas about approaches to the final solution, which by definition, is a part of the Storyboarding subprocess (see appendix K).

As for the difference across knowledge uncertainty during Solution Option Generation, a potential explanation for this finding may lie within the definitions of several other subprocesses and the nature of the manipulation in the dynamic knowledge condition. During the dynamic knowledge condition, selected information (e.g., location of the rebel forces and the weather) was changed through an update provided by the experimenter at a standard time during the experiment. This meant that for these teams in the dynamic knowledge condition, the new information cause changes to their original plan. In other words, the solution options that they may have already generated may need to be changed based on the newly changed information. Once a team began to make changes to their original plan, the raters needed to look at the definitions of several other subprocesses that relate to changes made to the original plan, including Team Negotiation of Solution Alternatives and Replanning (see appendix K). While brainstorming and initially coming up with ideas for the final plan were coded as the Solution Option Generation subprocess, changes made to these solution options were coded as either the Team Negotiation of Solution Alternatives or Replanning subprocesses. By design, the nature of the dynamic knowledge condition often caused teams to need to make changes to their initial plan. Therefore, a lower percentage of time ended up coded as Solution Option Generation because the ideas and suggestions generated as possible solution options after the experimenter updated the information differed from the initial plan and, therefore, needed to be coded as one of several other subprocesses.

The macrocognitive subprocesses were also examined in terms of how they were nested within each of the macrocognitive major-processes. These results are shown in figure 9. Examination of the differences across collaboration mode and knowledge uncertainty for the subprocesses nested within the major macrocognitive processes revealed some significant differences. Within Individual Knowledge Building, face-to-face teams spent a larger percentage of their time engaged in the subprocesses of Knowledge Interoperability, Visualization and Representation of Meaning, and Building Common Ground than asynchronous-distributed teams. Asynchronous-distributed teams, however, spent more time engaged in Knowledge Sharing during Individual Knowledge Building than face-to-face teams. When compared to the overall results for the occurrences of these subprocesses, Knowledge Interoperability, Visualization and Representation of Meaning, and Building Common Ground were each, once again, both found to occur at a higher rate in the face-to-face teams than the asynchronous-distributed teams. A new difference across collaboration mode that emerged when examining the nesting within Individual Knowledge Building; however, was that asynchronous-distributed teams spent more time in the Knowledge Sharing subprocess.

During Individual Knowledge Building, when team members ask for clarification of data or information, or respond to a clarification that was requested by other team members (see appendix J), the fact that asynchronous-distributed teams spent a higher percentage of time (over face-to-face teams) passing pieces of information to another team member (a.k.a., Knowledge Sharing, see appendix K) seems very reasonable. In fact, in their discussion, Warner, Letsky, and Cowen (2005) summarized their original results regarding the differences between asynchronous-distributed and face-to-face communication patterns. They stated that asynchronous-distributed teams seemed to focus more than face-to-face teams on individual convergence of data to knowledge in order to build knowledge and sharing knowledge (see Warner, Letsky, and Cowen, 2005). The current re-analyses also seems to support this pattern of communication for asynchronous-distributed teams.

For the macrocognitive major process of Team Knowledge Building, there were significant differences across collaboration mode as well. While engaging in Team Knowledge Building, face-to-face teams spent more time than asynchronous-distributed teams in the following subprocesses: Individual Task Knowledge Development, Individual Mental Model Development, Knowledge Interoperability, Visualization and Representation of Meaning, Knowledge Sharing, Team Shared Understanding, and Building Common Ground. These results are not surprising since overall, face-to-face teams spent a significantly larger percentage of time than asynchronous-distributed teams engaged in Team Knowledge Building. Team Knowledge Building is the major process under which all team members participate in clarifying information in order to build team knowledge (see appendix J). Once again, the present re-analyses provide further support for the communication patterns found by Warner, Letsky, and Cowen (2005): asynchronous-distributed teams spent more time than face-to-face teams on the individual convergence of data to knowledge in order to build team knowledge.

During Team Knowledge Building, one subprocess was found to occur in the asynchronous-distributed condition more often than the face-to-face condition. The Storyboarding subprocess during Team Knowledge Building occurred more frequently during asynchronous-distributed team collaboration than during face-to-face. This finding is reflective of the overall results for this subprocess, for which overall, Storyboarding occurred more often in the asynchronous-distributed teams than in the face-to-face. Once again, it is likely the type of environment used during the experiment to make asynchronous-distributed collaboration possible made participants more likely to engage in “storyboarding”-like behaviors.

Within Developing Shared Problem Conceptualization, there were only two significant differences across collaboration mode. During Developing Shared Problem Conceptualization, asynchronous-distributed teams spent more time engaged in Individual Task Knowledge Development than face-to-face teams. This is not surprising, given the results of the overall analyses of this subprocess. Overall, asynchronous-distributed teams spent a larger percentage of time engaged in the Individual Task Knowledge Development subprocess than face-to-face teams. The results of the analyses of Individual Task Knowledge Development within the Developing Shared Problem Conceptualization major process simply reflect the finding of the more general results. During Developing Shared Problem Conceptualization, the other subprocess for which there was a significant difference across collaboration was Storyboarding. Once again, this result reflects the overall findings for this subprocess. Asynchronous-distributed teams engaged in the Storyboarding subprocess more often than face-to-face teams. Finally, there were no significant differences during Developing Shared Problem Conceptualization across knowledge uncertainty.

The last major macrocognitive process, under which there were significant differences across either collaboration mode or knowledge uncertainty for the subprocesses nested within, was Team Consensus Development. During Team Consensus Development, asynchronous-distributed teams spent more time than face-to-face teams engaged in Iterative Information Collection, Individual Task Knowledge Development, Solution Option Generation, and Storyboarding. All four of the findings for these subprocesses nested within the Team Consensus Development major process reflect the general results for the same subprocesses and are, therefore, not surprising. Within the Team Consensus Development major process, face-to-face teams spent more time than asynchronous-distributed teams engaged in the following subprocesses: Knowledge Interoperability, Visualization and Representation of Meaning, and Building Common Ground. Again, these nested results, not surprisingly, reflect the overall findings for each of these subprocesses. Finally, as was found in the overall analyses for the Solution Option Generation subprocess, the analyses of this process during Team Consensus Development revealed that the teams in the static knowledge condition spent more time in Solution Option Generation than teams in the dynamic knowledge condition.

In order to complete a new taxonomy based on the revised definitions proposed by Letsky and colleagues (2007), the macrocognitive subprocesses were also examined in relation to the team collaboration stages. The overall results regarding the new taxonomy of the collaboration stages, macrocognitive major processes and subprocesses are shown in figure 10. There were also some significant findings regarding differences across collaboration mode and knowledge uncertainty within the subprocesses when they were analyzed nested under the team collaboration stages that they support. During Knowledge Construction, face-to-face teams spent more time than asynchronous-distributed teams engaged in the following subprocesses: Knowledge Interoperability, Visualization and Representation of Meaning, Knowledge Transfer, and Team Shared Understanding. These results are not surprising for two reasons. The first reason is that the overall results when the collaboration stages were analyzed independently from the subprocesses that support them were that face-to-face teams spent more time in the Knowledge Construction stage than the asynchronous-distributed teams. The second reason is that the analyses for the subprocesses independent of the team collaboration stages revealed that, for both Knowledge Interoperability and Visualization and Representation of Meaning, a larger percentage of time was spent in these subprocesses by face-to-face teams than teams in the asynchronous-distributed condition.

During the Collaborative Team Problem Solving stage, face-to-face teams spent more time engaged in Individual Mental Model Development, Knowledge Interoperability, Visualization and Representation of Meaning, and Building Common Ground than asynchronous-distributed teams. One explanation for these results is that they reflect the overall findings for each of these subprocesses when analyzed independently of the team collaboration stages that they support. However, asynchronous-distributed teams spent more time engaged in Individual Task Knowledge Development, Solution Option Generation, and Storyboarding, than face-to-face teams during the Collaborative Team Problem Solving stage. These differences between the two collaboration modes seem to reflect the overall results of the team collaboration stages when analyzed independently from the macrocognitive subprocesses. Overall, the asynchronous-distributed teams spent significantly more time in the Collaborative Team Problem Solving stage than the teams in the face-to-face condition. Therefore, the fact that three of the subprocesses that support this stage reflect this generalized finding seems very logical. During Collaborative Team Problem Solving, there was also a significant difference found between the uncertainty conditions for the subprocess of Solution Option Generation. Teams in the static knowledge condition spent more time engaged in Solution Option Generation than teams in the dynamic knowledge condition. Once again, this finding reflects the overall results, independent from the collaboration stages, for this subprocess, and was therefore, not surprising.

During the Team Consensus stage, significant differences were only found for two subprocesses. Face-to-face teams spent more time than asynchronous-distributed teams engaged in both Knowledge Interoperability and Visualization and Representation of Meaning. Once again, both of these subprocesses were found to more commonly occur during face-to-face team collaboration than asynchronous-distributed collaboration when analyzed independently from the team collaboration stages. Within the Team Consensus stage, there were no significant differences across the knowledge uncertainty conditions. Finally, during the Outcome, Evaluation, and Revision stage, there were no significant differences found for any of the subprocesses across either collaboration mode or knowledge uncertainty.

HOW TEAMS TRANSITION BETWEEN THE TEAM COLLABORATION STAGES

As was mentioned in the Introduction section of this report, both the team collaboration stages and macrocognitive processes are dynamic in nature. The results of the analyses of the transition probabilities between the team collaboration stages revealed that there were no significant differences across knowledge uncertainty; however, there were differences across collaboration modes. The transition probabilities for the team collaboration stages are shown in figure 11 (see also, Warner and Wroblewski, 2005; 2006). There were significant differences across collaboration mode for the following stage-to-stage transitions: from Knowledge Construction to Collaborative Team Problem Solving, from Collaborative Team Problem

Solving to Knowledge Construction, from Team Consensus to Knowledge Construction, from Team Consensus to Collaborative Team Problem Solving, from Outcome, Evaluation, and Revision to Knowledge Construction, from Outcome, Evaluation, and Revision to Collaborative Team Problem Solving, and from Outcome, Evaluation, and Revision to Team Consensus. For each of these transitions, the probability of occurrence was higher for the asynchronous-distributed teams than for the face-to-face teams. However, when you look at the probabilities for teams to stay within the same stage between lines of utterances (e.g., one statement falls under Knowledge Construction and so does the next line); all of the probabilities are significantly higher in the face-to-face condition than the asynchronous-distributed condition. The means that face-to-face teams, on average, were more likely to have a number of consecutive lines of text in the transcripts coded as the same stage, whereas teams in the asynchronous-distributed condition were more likely to transition between the stages during their conversations. The most likely explanation for this finding is that the conversations in face-to-face condition more closely resembled a normal everyday conversation involving three people talking while in the same room. The conversation flowed from one topic to another in a smooth manner with few abrupt transitions. In the asynchronous-distributed condition, however, this type of natural flow did not appear to take place. Rather, team members communicated in brief statements, and jumped around, not only from topic to topic, but also from team collaboration stage to collaboration stage.

Another explanation for the seemingly abrupt and frequent transitions between the collaboration stages may be that teams in the asynchronous-distributed condition only spent time typing what they absolutely needed to ask or convey to others. This was noted by Warner, Letsky, and Cowen (2005), and they proposed that the structure of the EWall environment permitted more effective and focused communication. They suggested that EWall helped teams to focus on team problem solving behaviors (e.g., as was discussed earlier, asynchronous-distributed teams spent a significantly higher percentage of time in the Collaborative Team Problem Solving stage than the face-to-face teams) and helped team members to communicate only the most relevant information and knowledge to each other. This notion was further supported by the fact that asynchronous-distributed teams made significantly fewer utterances in all four of the team collaboration stages compared to the face-to-face teams. The asynchronous-distributed teams did not differ, however, from the face-to-face teams in terms of the amount of time needed to complete the task, or in terms of their performance (e.g., the quality of their solution). This means that they achieved the same high quality solution in the same amount of time, but the asynchronous-distributed teams simply required less communication than teams in the face-to-face condition. Once again, Warner, Letsky, and Cowen (2005) suggested that this was because EWall facilitated a more effective mode of communication and collaboration compared to the face-to-face collaboration mode.

HOW TEAMS TRANSITION BETWEEN THE MACROCOGNITIVE MAJOR PROCESSES

For the macrocognitive major processes, overall, there were a number of transition probabilities that occurred a significant amount of the time (see figure 12). There were no significant differences across knowledge uncertainty regarding transitions between the macrocognitive major processes. However, there were a number of significant differences between the asynchronous-distributed and face-to-face conditions for the major process to major process transition probabilities. Specifically, teams in the face-to-face condition were more likely than teams in the asynchronous-distributed condition to transition from: Individual Knowledge Building to Team Knowledge Building, Team Knowledge Building to Individual Knowledge Building, Team Knowledge Building to Team Consensus Development, and Team Consensus Development to Team Knowledge Building. Teams in the asynchronous-distributed condition were more likely than teams in the face-to-face condition to transition from: Individual Knowledge Building to Developing Shared Problem Conceptualization, Developing Shared Problem Conceptualization to Individual Knowledge Building, Developing Shared Problem Conceptualization to Team Consensus Development, and Team Consensus Development to Developing Shared Problem Conceptualization.

These results, when compared to the overall macrocognitive major process occurrence rates broken down by collaboration mode, seem very plausible. Teams in the face-to-face condition spent a larger percent of time engaged in the Team Knowledge Building major process than teams in the asynchronous-distributed condition. Therefore, transition probabilities both beginning and ending in this major process were higher for the face-to-face teams. Teams in the asynchronous-distributed condition spent more time than teams in the face-to-face condition engaged in the major process of Developing Shared Problem Conceptualization. This reflects the finding that asynchronous-distributed teams spent a larger percentage of time engaged in Developing Shared Problem Conceptualization than face-to-face teams. Therefore, it seems very reasonable that, when examining the transition probabilities, all of those that were found to occur more often in the asynchronous-distributed condition than in the face-to-face condition either began or ended in Developing Shared Problem Conceptualization. These results, once again support the findings of Warner, Letsky, and Cowen (2005) that asynchronous-distributed teams tended to focus on sharing knowledge, whereas, face-to-face teams tended to employ many more processes to build knowledge.

EXAMINING CONSISTENCY AND CONTRIBUTION

Warner, Letsky, and Cowen's (2005) research examined the consistency and contribution of the team collaboration stages and macrocognitive subprocesses from earlier versions of the taxonomy and definitions. Their findings led to the revised version of the taxonomy and definitions proposed by Letsky and colleagues (2007). While there were a number of changes to the macrocognitive subprocesses, the team collaboration stages remained unchanged. In addition, the new taxonomy included the five macrocognitive major processes.

For the team collaboration stages, Warner, Letsky, and Cowen (2005) concluded that there were significant differences regarding the contribution of the stages during problem solving that were domain dependent. Specifically, teams solving fixed solution collaborative problems (e.g., the murder mystery scenario) did not go through the Outcome, Evaluation, and Revision stage, whereas teams that collaborated on problems where they needed to develop optimized solutions (e.g., the NEO scenario) spent a significant amount time in each of the four stages outlined in their model (see figure 1). Since the present re-analyses used the transcripts from the same NEO scenario experiment that Warner, Letsky, and Cowen (2005) used in their second experiment, no additional information about the consistency of the team collaboration stages across different problem solving domains was obtained. However, additional information was obtained related to how dependent the coding of the team collaboration stages was upon the raters who went through the transcripts. Originally, the interrater reliability between the two raters for Warner, Letsky, and Cowen's (2005) study was 0.80. For the present re-analyses, two new raters, using the same definitions and examples coded a subset of the transcripts for the team collaboration stages. The interrater reliability between the two new raters was also 0.80. Therefore, it seems that different raters can code a transcript for the team collaboration stages with a high degree of consistency and that these stages are not dependent upon the raters themselves.

As for their contribution, there were two major differences for the team collaboration stages across collaboration mode. Face-to-face teams spent a larger amount of time than asynchronous-distributed teams in the Knowledge Construction stage. Asynchronous-distributed teams spent more time than teams in the face-to-face condition in the Collaborative Team Problem Solving stage. Based on the definitions provided by Letsky and colleagues (2007), teams in the face-to-face conditions, therefore, spent more time reading, clarifying information, and trying to understand the problem. Asynchronous-distributed teams spent a larger percentage of their time communicating and analyzing data and knowledge to develop solution options, developing, rationalizing, and discussing alternative approaches. These results regarding the contributions of the team collaboration stages were consistent across both of the original experiments performed by Warner, Letsky, and Cowen (2005), and the present re-analyses.

Since the macrocognitive major processes were new additions to the revised taxonomy (see Letsky, et al., 2007), the consistency and contribution of these processes across different domains has yet to be studied. However, the results of the present analyses revealed that, overall, all five processes were significant and contributed to the problem solving process. The interrater reliability between the two raters was 0.82, which is similar to the interrater reliability for the team collaboration stages. This result seems promising in terms of the orthogonality of the definitions. Since the interrater reliability was high, it seems as though the two raters were able to distinguish between each of the macrocognitive major processes during the coding process. One of Letsky and colleagues' (2007) goals was to have orthogonal definitions for the processes. Although future research will need to examine further these major processes and their consistency across different domains, the initial results of the present research seem encouraging.

Examination of the macrocognitive major processes also revealed that there were several differences between the two collaboration modes. The asynchronous-distributed teams were significantly more likely than face-to-face teams to spend a greater percentage of the time engaged in Developing Shared Problem Conceptualization. Teams in the face-to-face conditions, however, spent significantly more time in the Team Knowledge Building process that asynchronous-distributed teams. Examination of the transition probabilities between the macrocognitive major processes was a second way in which the contributions of the processes were looked at. The differences that were found for all five of the major processes in general were consistent with the analyses of the transition probabilities between the processes. As was discussed earlier, all of the transition probabilities that either began with or ended with the Team Knowledge Building major process were higher in the face-to-face condition than in the asynchronous-distributed condition. The transition probabilities that either started or finished with the Developing Shared Problem Conceptualization, on the other hand, were higher in the asynchronous-distributed condition than in the face-to-face condition.

Since the revised taxonomy (see Letsky, et al., 2007) included a number of new subprocesses and definitions (and changed or eliminated several of the old subprocesses), a full comparison was not possible across all of the subprocesses between the original Warner, Letsky, and Cowen (2005) experiments and the present re-analyses. Some of the subprocesses, however, remained the same. The following subprocesses were significant across both sets of analyses: Iterative Information Collection, Individual Task Knowledge Development, Individual Mental Model Development, Knowledge Interoperability, Visualization and Representation of Meaning, Team Shared Understanding, and Solution Option Generation. For each of these seven macrocognitive subprocesses, their contribution to team collaboration during problem solving using the NEO scenario has shown consistency, even with changes to the other subprocesses in the taxonomy. In addition, the interrater reliability for the macrocognitive processes calculated between raters for Warner, Letsky, and Cowen's (2005) experiment was 0.57. The interrater reliability for the subprocesses for the present re-analyses was 0.71. This significant increase in the reliability between the two raters may be because the definitions are becoming more clear and understandable, the additional examples that were added were highly beneficial to the raters, and the revised set of definitions are more orthogonal than the original set (see Letsky, et al., 2007; Warner, Letsky, and Cowen, 2005).

For three of the subprocesses, the issue of orthogonality of the definitions was already raised earlier in the Discussion section. In Warner, Letsky, and Cowen's (2005) study, the macrocognitive process of Team Negotiation of Solution Alternatives was significant. In the revised taxonomy, however, two subprocesses were added that deal with assessing and/or changing solution options: Replanning and Feedback Interpretation (see Letsky, et al., 2007). The addition of these subprocesses with highly related definitions may have led to raters selecting one of the other two subprocesses during coding in some instances. This would explain why Team Negotiation of Solution Alternatives was not significant, but Feedback Interpretation was significant in the present re-analyses. Future research will need to examine this issue further.

In addition to the subprocesses already discussed, six more subprocesses were significant: Sharing Unique Knowledge, Knowledge Sharing, Knowledge Transfer, Critical Thinking, Building Common Ground, and Storyboarding. Along with Feedback Interpretation, these seven subprocesses were found to contribute a significant percentage of the time in supporting the team collaboration stages during the team problem solving process. However, unlike Iterative Information Collection, Individual Task Knowledge Development, Individual Mental Model Development, Knowledge Interoperability, Visualization and Representation of Meaning, Team Shared Understanding, and Solution Option Generation, there are only the results from the present re-analyses that provide support in regards to their significant contributions to team collaboration. Additional research will be needed in this area to further provide support concerning the contributions of these subprocesses, and will also need to address their consistency across different problem domains.

Research using different problem domains will also provide insight as to each of the new subprocesses that did not appear to contribute a significant percentage of the time during team collaboration using the NEO scenario (e.g., Uncertainty Resolution, Metal Simulation, Intuitive Decision Making, Replanning, Recognition of Expertise, etc.). For each of these subprocesses, a number of questions still need to be addressed. Are the definitions orthogonal with the other definitions? Is communication analysis the best way to accurately measure each of the subprocesses? Does the contribution of these subprocesses during team collaboration depend on the problem domain? These issues will be discussed further in the Future Research section of this report.

THE NEW TAXONOMY AND THE EVOLUTION OF THE TEAM COLLABORATION MODEL

The new taxonomy shown in figure 10 was based upon the empirical results of the present re-analyses. It summarizes the team collaboration stages, macrocognitive major processes, and subprocesses that had significant contributions to the team collaboration process. It shows which of the major processes supported the collaboration stages during the team problem solving process, and which subprocesses nested within each of the major processes. However, the taxonomy does not show how teams transition between the stages and the processes during team collaborative problem solving. The analyses that were performed on the transition probabilities facilitated a better understanding of these relationships. Combining the new empirically based taxonomy with the overall significant transition probabilities culminated in the team collaboration model shown in figure 13 (see also, Warner, Biron and Burkman, 2008). In the evolutionary process, the model shown here represents the logical next phase.

A brief example was included in a recent presentation of these re-analyses and the new model (Warner, Biron, and Burkman, 2008) in order to help explain the model and is included in appendix L. It includes a brief piece of a conversation, which can be used to describe the team collaboration stage, macrocognitive major and subprocesses associated with the excerpt. The example (see appendix L) included all three team members talking (e.g., the weapons expert, the environmental expert, and the intelligence expert). The weapon's expert began by asking a question to build knowledge and try to improve his/her understanding of about traveling times and distances. He or she was trying to clarify information, and while doing this, he/she referred other team members to a map. The second person to speak was the environmental expert. He/she tried to provide some clarification and answer the weapons expert's question without applying the knowledge to a solution. In addition, while trying to answer a teammate's question, he/she also used the visual representation of the previously referred to map. The last person to speak in this example is the intelligence expert. He/she answered the weapons expert's original question by using the map (e.g., measuring and reading information on the map) to transfer meaning and provide clarification to other team members.

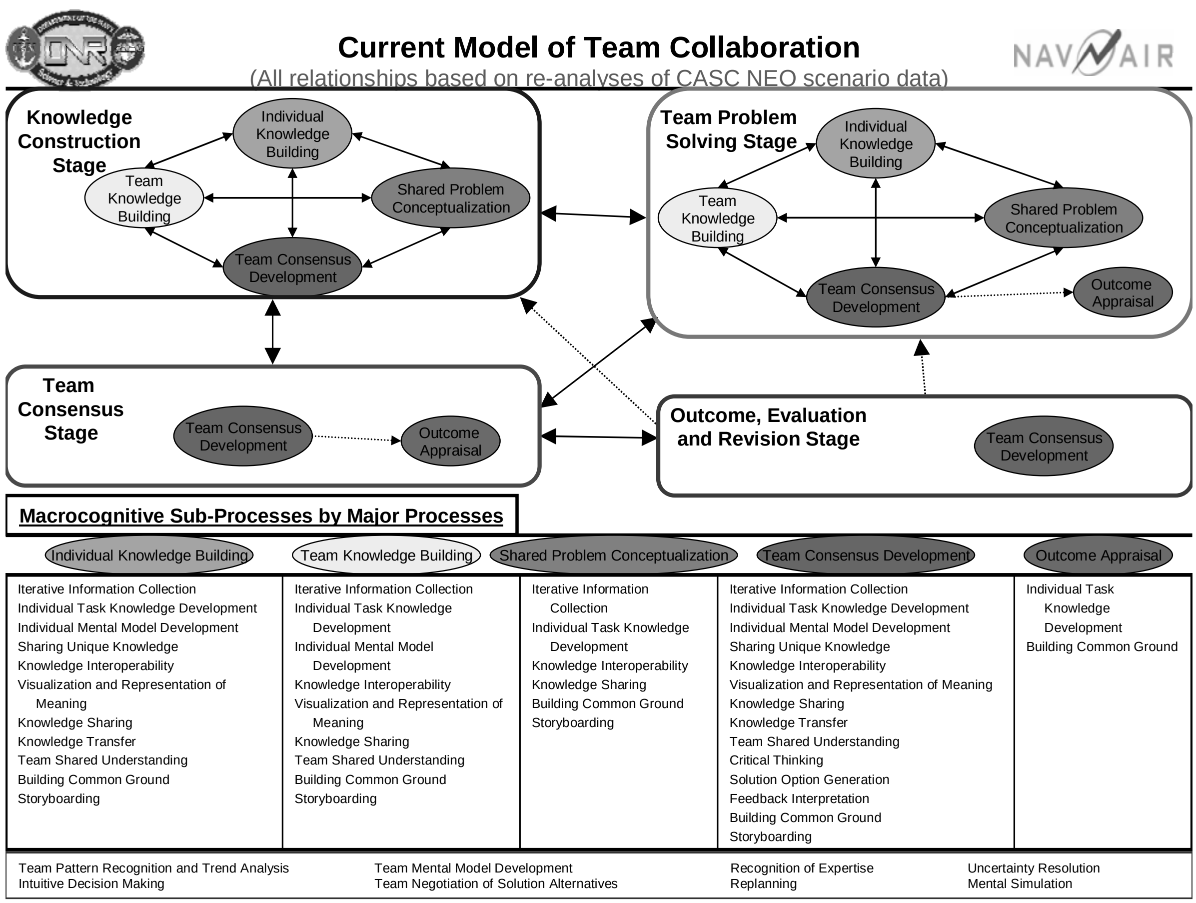

Figure 13: A New Team Collaboration Model

When team members are reading (e.g., information from a map), clarifying information and trying to understand the problem or some aspect of it (e.g., traveling times or distances) as they were in this example, they are engaged in the team collaboration stage known as Knowledge Construction (see Letsky, et al., 2007). From this example, it is also clear that all three team members are participating in trying to clarify information in order to build team knowledge. They are doing this through question asking and answering. Based on the definitions for the five macrocognitive major processes (see Letsky, et al., 2007; appendix J), this is classified as Team Knowledge Building. Finally, each of the team members spends time referring to the map. The map is a visual aid or representation, and the team's usage of it makes their questions and statement easy to classify as the macrocognitive subprocess of Visualization and Representation of Meaning (for all subprocess definitions see appendix K).

Figure 14 is a visual representation of this example based on the new team collaboration model shown in figure 13. It shows that, while working on a team collaboration task, the team members in the example were working within the Knowledge Construction stage and participating in Team Knowledge Building. While building knowledge, the team was using the macrocognitive subprocess of Visualization and Representation of Meaning. However, putting forth the team collaboration model in figure 13 and the accompanying example by no means exposes the complete nature of team collaboration, the stages, and the processes that support them. The example was included to help facilitate a better understanding of the model and how its components work together to represent the communication that took place during the teams' collaboration communication analyses data using the revised taxonomy and definitions proposed by Letsky and colleagues (2007), is still a work in progress in terms of fully expounding the team collaboration process. At the bottom of the model there are still macrocognitive subprocesses for which little is know to date about their contribution to the team collaboration process. Future research will need to address this, as well as a number of other aspects of the team collaboration process before a fully comprehensive and predictive model can be produced.

FUTURE RESEARCH

While the new taxonomy and model of team collaboration give insight as to how the teams collaborated on the NEO scenario, there is still a lot of research that needs to be done to determine the consistency and contribution of the collaboration stages, major and subprocesses across. For example, the team collaboration stages have been studied across different problem-solving domains in the lab (e.g., the murder mystery scenario and the NEO scenario; see Warner, Letsky, and Cowen, 2005), outside the lab through experiments, and in real world settings (e.g., the Maritime Interdiction Operations, the Air warfare decision making, and transcripts from the Firefighters from 11 September 2001; see Hutchins, 2008). However, the macrocognitive major processes have only been examined during the NEO scenario. In addition, while Warner, Letsky, and Cowen's (2005) study examined the contribution of subprocesses, some new subprocesses were added and others have been removed from the revised taxonomy and some of the definitions were changed (see Letsky, et al., 2007). Therefore, at this point, only a subset of the subprocesses have been examined across different domains (see Hutchins, 2008; Warner, Letsky, and Cowen 2005), and future research needs to examine both the major and subprocesses further to really assess their consistency and contribution. Future research in this area will also, hopefully, provide insight as to the contributions of some of the subprocesses that were not significant in the present re-analyses of the NEO data transcripts (e.g., Mental Simulation, Recognition of Expertise, Uncertainty Resolution, etc.), and subprocesses for which the degree of orthogonality with other subprocesses is uncertain (e.g., Feedback Interpretation, Replanning, and Team Negotiation of Solution Alternatives).

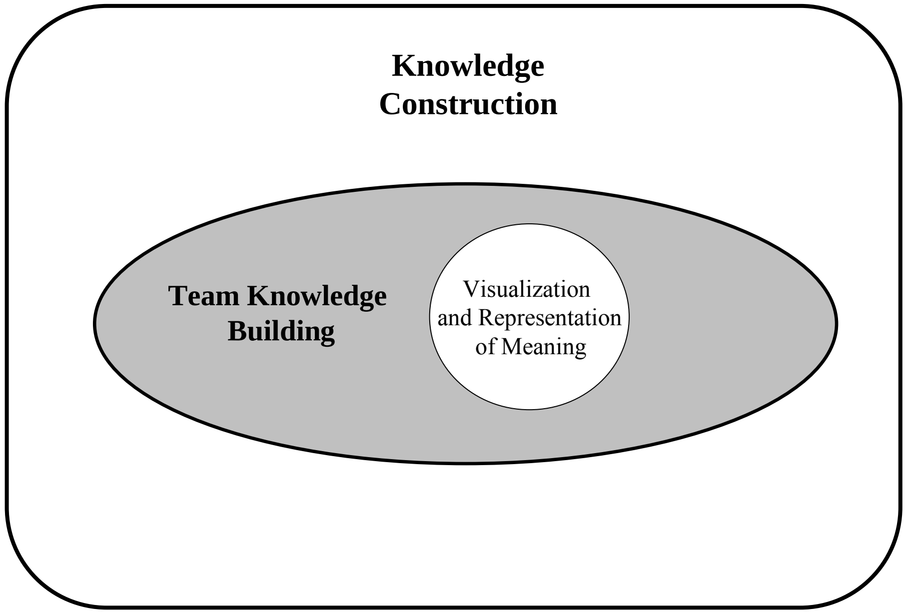

Figure 14: Visual Representation of the Example from Warner, Biron, and Burkman's (2008) presentation as it relates to the New Model of Team Collaboration

Another area for researchers who are interested in this area to investigate is how different measures can be used to examine the team collaboration stages and macrocognitive processes during problem solving. Some subprocesses, such as Mental Simulation, may not always be overtly expressed during the collaboration process. This subprocess may be one that takes place more internally. Therefore, communication analyses may not be the most accurate measure. For some of the subprocesses (e.g., Mental Simulation, Individual Mental Model Development, and Intuitive Decision Making) that may occur at a more internalized level, self-report measures maybe useful.

Some additional measures that may help to provide additional information about processes that contribute to the team collaboration process during problem solving. For example, eye-tracking measures and analyzing gestures that team members make during collaboration may provide information about attention and nonverbal communication that raters cannot code during communication analyses. Research that includes these measures (and others) may also help to provide additional information about how nonovert responses may affect the findings for processes defined as including *all* team members, and in general, because having multiple measures would be useful for examining both contribution and constancy of the macrocognitive processes during team collaboration.

Another major area that still needs to be addressed in future research is team differences. There may be differences in how teams collaborate based on a number of different variables. For example, although Warner, Letsky, and Cowen (2005) did not find any performance differences across either of their two independent variables (e.g., knowledge uncertainty and collaboration mode), for some problem domains, there may be differences in how high performing (e.g., teams that score high on predetermined performance measures) and low performing teams collaborate. Some other variables that are listed in Warner, Letsky, and Cowen's (2005) team collaboration model (see figure 1) that may affect how team collaborate include: unique roles, cultural diversity, and time pressure. In addition, although Warner, Letsky, and Cowen (2005) did not find many significant differences across knowledge uncertainty, perhaps more differences might exist across different problem domains or through different ways of manipulating knowledge uncertainty (e.g., more changes in the data). Hutchins (2008) discusses differences across different problem domains as well. For example, she discussed team collaboration differences between mission planning and mission execution scenarios and proposed that an additional subprocess, Request to Take Action, had a significant contribution during team collaboration that involved mission execution (e.g., the transcripts from the Firefighters from 11 September 2001). Depending on the problem domain and the variables being studied, researchers may discover additional subprocesses that have significant contributions as well.

Future research should address all of these issues in order to foster a better understanding of how teams collaborate during different types of problem solving tasks. Specifically, researchers need to focus on examining the contributions and consistency of the collaboration stages and macrocognitive major and subprocesses. Consequently, this should lead to the development of a strong empirically-based model of team collaboration and help guide researchers toward developing the best possible team collaboration tools.

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CONCLUSIONS

The goal of this research was to facilitate a better understanding of the process of team collaboration. Through re-analyzing previously collected data transcripts using the revised taxonomy and definitions proposed by Letsky and colleagues (2007), an examination of the consistency and contributions of the collaboration stages, macrocognitive major processes, and subprocesses was possible. The results of the re-analyses support the contribution of the four collaboration stages during the process of team collaboration, with the caveat that their consistency appears to be domain dependent. The contribution of all five major macrocognitive processes during team collaboration was also significant. However, whether or not this result is also dependent upon the problem-solving domain is still unknown. The results of the present re-analyses also provided support for some of the macrocognitive subprocesses in terms of both their consistency and contribution. There were also significant differences, depending on the collaboration mode used by the teams, in terms of the collaboration stages, macrocognitive major processes, and macrocognitive subprocesses. Based on these results, the next phase in the evolution of the conceptual model of team collaboration was proposed. However, the model will no doubt continue to evolve since future research is still needed to further examine the consistency and contribution across different domains and in terms of different types of teams.

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APPENDIX A
THE NONCOMBATANT EVACUATION OPERATION: RED CROSS RESCUE SCENARIO

THE MISSION:

The time is 2:00 am, January 15th. Three American Red Cross workers are trapped in a church basement on a remote island in the South Pacific, caught in the middle of guerilla warfare. Your mission is to rescue them within 24 hr.

The situation is described in the next few pages along with the assets of U.S. forces available to rescue the workers. Work together to develop a course of action, using ANY assets available to you. The detailed plan can be made up of Army, Marine, or Navy Seal assets (or a combination of the three), but must include the following:

- a description of how the rescuers will get to the church
- a description of how they will evacuate the Red Cross workers
- and a description of how they will return to the Army base or aircraft carrier.

Choose the best and most efficient solution to rescue the workers safely. Minimize damage to the village and villagers, and avoid contact with the enemy if possible. Keep in mind, however, the rules of engagement state that any forces will defend themselves if needed.

Good Luck!

BACKGROUND INFORMATION:

Drapo Island

Date:

January 15th, 0200 (2:00 AM), Drapo Time Zone

Location:

Drapo Island, located 750 miles north of Australia, slightly northeast of the Solomon Islands.
(See Map 1)

Size:

The island is 400 miles wide by 400 miles long.

Topography:

Drapo Island is made up of volcanic mountains, atolls (ring-like coral island and reef), some swampy lowlands, and rugged mountainous terrain with some low dense rainforest. Because much of the island is made up of volcanic mountains, there is a constant threat of volcanic activity. The terrain consists of coastal plains, swampy lowlands, a large rainforest and mountain ranges.

Location:

The church where the workers are trapped is located 3 miles from the northern-most shore of the island. Directly in front of the church is a dirt road, which leads to the ocean in one direction and into the main village on the island in the other direction. The village is 1.5 miles from the church. The road also passes homes and farms of the natives on the way into the town. The church has some vegetation around it, primarily coconut trees and some brush, but no heavy forest or swampland. The land around it is mostly cultivated for farming.

A small port is located on the opposite end of the island from the church, and is heavily guarded by the local military. To reach the church from the port, you must cross an uninhabited volcanic mountain pass, which is covered by dense rainforest.

Because of the coral reefs, it is impossible to bring large ships any closer than 1 mile from the coast. The shore is only accessible by small boats. Significant amounts of coral can be seen above the surface of the water at low tide.

There is one paved highway around the perimeter of the island. This road also leads to the dirt road where the church is located. **(See Maps 2 and 3)**

Climate and Weather:

The climate on Drapo is tropical with rainy seasons from December through March and May through October. There are also periodic tropical monsoons. In January, there are periods of heavy fog in the morning, which burns off as the day progresses. Visibility is usually clear by noon. There are strong winds throughout the day.

Military:

The local military is made up of about 100 volunteers who support their government. It has recently been built up in response to increasing threats from rebel forces. The government has limited military intelligence and limited analysis capability. Drapo is in good and peaceful standing with the United States.

Village:

The village is home to the government center, school, church, markets, and communication center for the island. Any weapons and military intelligence possessed by the island will be centered in the village. The majority of the island's homes are located within 1 mile of the village. There are between 100 and 150 huts housing 5 to 10 natives each. The village is about 1.5 miles from the church and 4.5 miles from the northern-most point of the island.

The local language is Draponese. The locals do NOT speak English, so if any attempt is going to be made to communicate with the local military, a translator will be needed.

Transportation:

One main paved highway surrounds the perimeter of the island. **(See Map 2)** Dirt roads connect the airport, homes, village, and the church where Red Cross workers are trapped.

There is one main port, which is used for the export and import of goods. Directly off the shore of most of the island are atolls, which make it impossible for large ships to come within 1 mile of the shore (with the exception of the port).

There is one main airport with a paved runway, located 200 miles from the village. The airport is heavily guarded by the local military to keep rebel forces out. The airport flies into Australia, the nearest mainland (750 miles away), and from there can connect to other countries. **(See Map 3)**

Communication:

Communication on the island and off the island is possible, but is limited by the remoteness of the island. The Red Cross workers have working mobile phones; however, the batteries died soon after they contacted the American Red Cross Headquarters. The church where the workers are trapped does not have a telephone. There is limited radio communication on the island (three 3 AM, no FM stations). There are no television stations on the island. Internet access on the island is limited to government workers only.

Condition of Red Cross Workers:

The workers are somewhat safe in one room of the church. They have no source of water except rainwater. They are able to collect food easily from areas around them but that supply is limited and venturing too far to collect food is dangerous. Rescuers should be aware that workers will most likely be dehydrated and suffering from malnutrition.

One of the workers is a diabetic in need of insulin. He will most likely go into insulin shock if not treated within 24 hr. Another worker has a broken leg. The third worker appears to be healthy at this time. There is a chance that workers could be injured from the outside warfare and that their location may not be safe for long. They must be rescued within 24 hr.

REBEL FORCES:

- The Rebel Forces consists of 500 trained soldiers.
- They guard the perimeters of their captured areas at ALL times.
- They have no night vision capability.
- The have Stinger missiles. (Stinger missiles are hand-held, infrared, heat-seeking rockets with a range of 1 – 5 miles.)
- Their small arms fire consists of M-16 rifles (range: 500 yd) and 9mm pistols (range: 25 yd).
- They have land mines. (It is possible that local roads might be mined.)
- Their weapons storage, communication centers, and anti-aircraft locations are not known to the U.S or Drapo military.
- They have rocket propelled grenades.
- Warfare is constant between rebels and local military.
- They have easy access to trucks and jeeps.
- They are aware the Red Cross workers are on the island, but unaware of their exact location. They are on-guard for possible rescue operations.

NAVY SEALS ASSETS:

Personnel:

- 7-man squad consisting of:
  - ~ 1 Corpsman
  - ~ 1 Radioman
  - ~ 1 Heavy Gunners
  - ~ 2 Riflemen with M-16 rifles
  - ~ 2 Riflemen with M-16 rifles and grenade launchers
- Night vision capability.
- Need local translator if communicating with villagers.
- Ability to be virtually undetected.
- All Navy SEALS are trained as medics.
- Navy SEALS usually initiate covert operations from the sea.
- All weapons and personnel are located on the USS ENTERPRISE.
- The USS ENTERPRISE has full medical facilities.

Transportation and Weapons:

Navy Seahawk (SH-60): A twin-engine helicopter used for antisubmarine warfare, drug interdiction, cargo lifts, and special operations in the day or night regardless of the weather conditions.	

Navy Hornet (F-18): A one or two seat supersonic jet used for air-to-air (A/A) or air-to-ground (A/G) support.	
Zodiac: A 7-man inflatable boat which can travel at speeds up to 15 mph.	

ARMY SPECIAL FORCES ASSETS

<u>Personnel</u>:

- 6-man Special Forces team consisting of:
  - ~ 1 Team Lead
  - ~ 2 Snipers
  - ~ 2 Team Medics
  - ~ 1 Translator (Speaks several languages, but NOT Draponese.)
- Highly trained in multiple languages.
- Night vision capabilities.
- Weapons: M-16, M-60, grenades.
- Army Special Forces usually initiate covert operations from the land.

<u>Transportation and Weapons:</u>

Abram Tanks: Used for enemy suppression.	
Blackhawk Helicopter (UH-60): A twin-engine helicopter used for special operations in the day or night, regardless of the weather conditions.	

AH-64 Apache: A twin-engine helicopter used for enemy suppression.	
C-130 Hercules: A large aircraft used for troop and cargo transport, paratrooper deployment, and airborne refueling.	

MARINE ASSETS

Personnel:

- 12-man team that includes:
  - ~ 2 Medical Corpsmen
  - ~ Use of M-16, M-60, grenades
  - ~ Night vision capabilities
- Marine personnel are stationed on the USS ENTERPRISE.

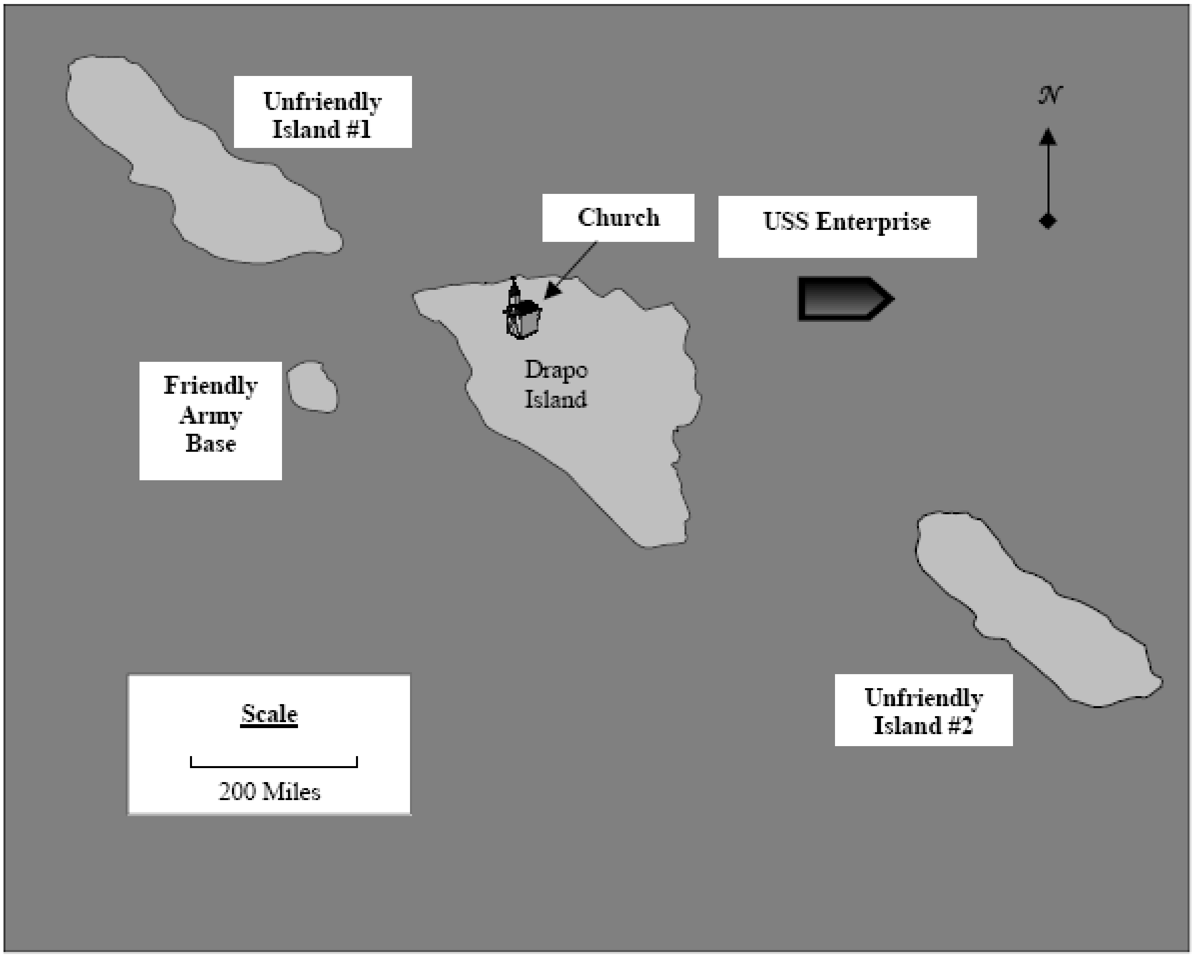
Transportation and Weapons:

AH-1: An attack force helicopter used to suppress enemy troops and provide air support.	
CH-53: A cargo/transport helicopter used in amphibious and shore operations.	

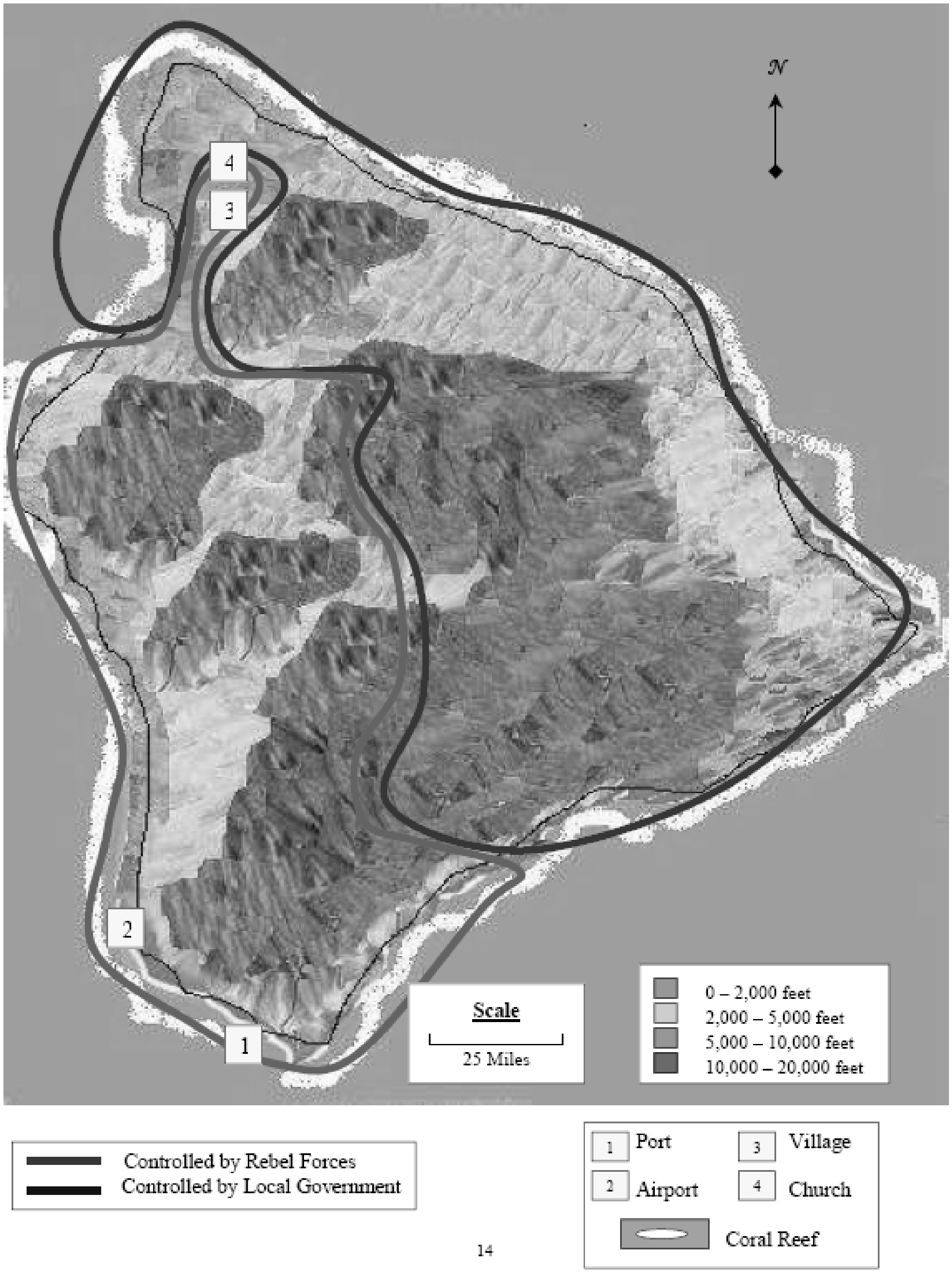
MAPS

The South Pacific Island of Drapo

Map 1 - Drapo Island



Map 2 - Drapo Island



Map 3 - North Shore of Drapo Island

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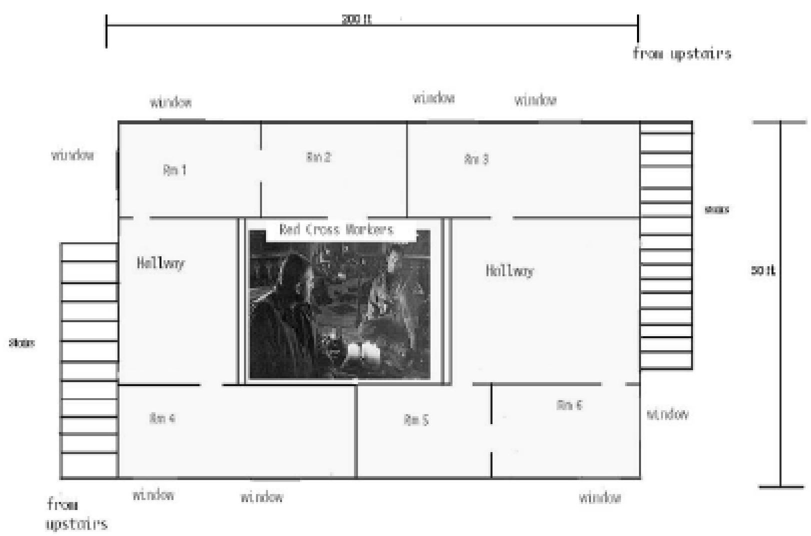
APPENDIX B
ENVIRONMENTAL EXPERT INFORMATION

- Coral reefs are impassable except during high tide.
- Highest peaks in the mountain range reach 20,000 ft, while the lowest peaks reach 5,000 ft.
- The water temperature is 84^{o}F.
- Daytime temperature is 90^{o}F.
- Night temperature is 80^{o}F.
- Fog is present on the island from 6 am to 12 noon.
- Sunrise occurs at 6 am.
- Sunset occurs at 7 pm.
- While Drapo is home to many indigenous animals, no snakes can be found on the island.
- High tide is between 7 and 9 am and 8 and 10 pm.
- On average, high tide is about 2 ft.
- The rebels can see 12 miles from the beach (the distance of the horizon).
- The morning of 15 January, there is heavy fog and light drizzle. The night of 16 January, there is a full moon, cloudy skies, and light drizzle.
- The waters around Drapo are a breeding ground for Great White sharks and barracuda.

APPENDIX C
INTELLIGENCE EXPERT INFORMATION

- It takes a SEAL team or an Army Special Forces team 45 min to reach the church from the shore.
- It takes a SEAL team or an Army Special Forces team 30 min to reach the church from the village, and 30 min to return to the village.
- Airfield has fuel available if ground refueling is needed.
- Navy SEAL and Army Special Forces teams can parachute from a C-130 (day or night).
- Church layout – see below.
- Initial contact has been made with local military.
- SEAL and Army Special Forces teams can use element of surprise.
- U.S. Army Special Forces are currently using a deserted army base for training. The base is 200 miles west of the church where the workers are trapped.
- The deserted army base where the Special Forces are training and the aircraft carrier USS ENTERPRISE are considered safe locations.
- The USS ENTERPRISE is anchored 200 miles east of the church.
- The airport is 200 miles from the village.
- The local military has three Toyota trucks, bikes, and donkeys available for U.S. force transportation.

Church Floorplan:



APPENDIX D
WEAPONS EXPERT INFORMATION

- Riflemen carry M-16s (effective range 500 yd) and grenades
- Small arms fire can disable low-flying aircrafts
- Heavy gunners in SEAL unit carry M-60s (large caliber machine guns) with a range of 1,500 yd.
- Suppressive fire by aircraft can be used to keep rebels from interfering with rescue mission, but collateral damage can result.
- Helicopters can be heard for 5 miles.

❖ U.S. Navy or Marine F-18 Hornet:
~ One or two seat supersonic jets that can be used for A/A or A/G support
~ Speed: Mach 1.7+
~ Range: 1,500 miles (Range is defined as the total miles that can be flown without refueling.)
~ Ceiling: 50,000 ft
~ Weapons: A/A missiles, A/G smart bombs, 6,000 rounds per minute cannon
~ Can be flown in any weather, day or night
~ In-flight refueling capabilities
~ F-18s are located on the USS ENTERPRISE

❖ U.S. Army Blackhawk (UH-60) OR U.S. Navy Seahawk (SH-60):

~ Twin engine helicopter used for special ops in any weather, day or night
~ Speed: 184 mph
~ Range: 395 miles
~ Ceiling: 14,700 ft
~ Weapons: Two machine guns and missiles for A/A and A/G support
~ Rescue hoist cable: 250 ft with a 600 lb lift capacity
~ Can be refueled in flight
~ Crew: 4
~ Can carry 11 additional people
~ Blackhawks are located on the deserted army base where the Army Special Forces are conducting their exercises
~ Seahawks are based on the USS ENTERPRISE

❖ U.S. Army Apache (AH-64):
~ Twin engine helicopter used for suppression of enemy troops and enemy targets
~ Speed: 165 mph
~ Range: 372 miles
~ Ceiling: 12,500 ft
~ Weapons: Missiles for A/A or A/G support
~ Must be refueled on the ground

- ~ Crew: 2
- ~ Cannot carry any additional people
- ~ Located on the deserted army base

❖ U.S. Marine Cobra (AH-1):
- ~ Attack force helicopter used to provide air support (anti-armor, anti-helicopter, armed escort)
- ~ Speed: 170 mph
- ~ Range: 300 miles
- ~ Ceiling: 12,500 ft
- ~ Can fly day or night, but cannot fly in fog
- ~ Rescue hoist cable: 250 ft with a 600 lb lift capacity
- ~ Must be refueled on the ground
- ~ Crew: 2
- ~ Cannot carry any additional people
- ~ Located on the USS ENTERPRISE

❖ U.S. Marine CH-53:
- ~ Cargo/transport helicopter used in amphibious and shore operations
- ~ Speed: 200 mph
- ~ Range: 500 miles
- ~ Ceiling: 21,000 ft
- ~ Weapons: None
- ~ Rescue hoist cable: 250 ft with a 600 lb lift capacity
- ~ Capable of refueling in flight
- ~ Crew: 3
- ~ Can carry 38 additional people
- ~ Cannot fly in fog
- ~ Two inflated Zodiacs can be air-dropped out the back ramp
- ~ Located on the USS ENTERPRISE

❖ U.S. Army Hercules (C-130):
- ~ A large aircraft used for troop and cargo transport, paratrooper deployment, and airborne refueling.
- ~ Speed: 335 mph
- ~ Range: 2,500 miles
- ~ Ceiling: 33,000 ft
- ~ Weapons: 7.62 mm mini-guns, 40 mm cannons, 105 mm cannon
- ~ Crew: 5 - 9
- ~ Can carry 92 additional people
- ~ Located on the army base being used for training exercises

- U.S. Army Abram Tank:
  - ~ Speed: 45 mph maximum (The Abram tank slows considerable when riding on a grade or slope.)
  - ~ Range: 275 miles
  - ~ Weapons: 105 mm rifled cannon, .50 caliber machine gun, 7.62 mm swivel mounted machine gun
  - ~ Crew: 4
  - ~ Requires jet fuel

- U.S. Navy Zodiac:
  - ~ A 7-man inflatable raft made of durable rubber and polyurethane fabric
  - ~ Speed: 15 mph
  - ~ Weight: 80 lb
  - ~ Can be deflated and stowed in minutes
  - ~ Sits flat on top of the water when empty
  - ~ 8 in. displacement when loaded to full capacity
  - ~ It takes approximately 1 hr to inflate with a hand pump
  - ~ Can be parachuted fully inflated from a height of no more than 2,000 ft from the back of a CH-53 or C-130.
  - ~ Zodiacs are considered expendable items

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APPENDIX E
SCORING MATRIX FOR THE NEO SCENARIO

Out of a possible 100 points.

Planning Card	Error	Error Type	Points Lost
Personnel	Omitting Personnel Card	A	20
Transportation	Omitting Transportation Card	A	20
	Using aircraft that requires in flight refueling without calculating refueling needs	C	5
	Calculation error rendering the solution impossible	C	5
	Using aircraft that requires in flight refueling (with correct calculations)	E	2
	Performing calculations incorrectly with minimal impact	E	2
	Using one aircraft that needs refueling, but others that don't.	D-E	2.5
Weapons	Omitting Weapons Card	A	20
	Using unavailable weapons	D	3
	Failing to address weapons used by selected military	D	3
Times	Omitting Times Card	A	20
	Failing to include required critical times (onset of operation, contact with workers, evacuation, return)	C	5
	Calculation error rendering the solution impossible	C	5
	Failing to account for tides or coral reef (if using sea approach)	D	3
	Rescuing workers during daylight hours	D	3
	Performing calculations incorrectly with minimal impact	E	2
	More than 0.5 hr spent in church	E	2
Plan	Omitting Plan Card	A	20
	Unrealistic solution (tanks, etc.)	B	10
	Neglecting to include all requirements of the plan as listed in the Mission Statement a. Getting to the church b. Evacuating the workers c. Returning to the base or ship	C	5 for each

Planning Card	Error	Error Type	Points Lost
	Failing to address medical treatment a. Insulin b. Broken leg	C	2.5 each
	Harming the enemy unnecessarily	C	5
	Damaging the village unnecessarily	C	5
	Failing to arrange for translator if need established	D	3
	Failing to address detection	D	3
	Failing to avoid detection if addressed	C	2
	Failing to avoid land mines	E	2
Miscellaneous	Other Type A error (e.g., omitting planning card)	A	20
	Other Type B error (e.g., serious violation of mission statement, unrealistic solution)	B	10
	Other Type C error (e.g., moderate violation of mission statement, calculation error with serious impact)	C	5
	Other Type D error (e.g., minor violation of mission statement)	D	3
	Other Type E error (e.g., calculation error with minimal impact)	E	2

APPENDIX F
EXPERIMENTER TRANSCRIPT: NEO INSTRUCTIONS
(FACE-TO-FACE CONDITION)

In the military, people often have to work together to solve problems. Sometimes those people are sitting around a table in the same room, but more often than not, they are scattered all over the world. One person may be at the Pentagon, one may be in California, and one may be in a cave in Afghanistan. Somehow all of these people have to work together to solve whatever problem they are working on. Right now, it is usually done through instant messaging and chat.

We want to help make that communication more efficient. But before we can do that, we have to understand how people work together to solve a problem. That is where you come in. I am going to give you a problem to solve and I want you to work together <u>as a team</u> to come up with a solution.

Here is the problem I want you to solve: Three Red Cross workers are trapped in a church basement on a remote island called Drapo. They're caught in a battle between the guerilla forces (the bad guys) and the Draponese military (the good guys). There are some U.S. military forces in the area who can help with the rescue.

Your job is to come up with a <u>realistic</u> plan to rescue the Red Cross workers using the U.S. military forces in the area. I will give you all the information you need to solve the problem. You <u>do not have to know anything</u> coming in to this. *{Show the binders that contain the NEO scenario and Expert Information.}* All of the information you need is in these binders. Almost all of the information is identical in all three binders. The last few pages, however, are different. Each one of you will be assigned an area of expertise. One of you will be the Weapons Expert, one will be the Environmental Expert, and one will be the Intelligence Expert. Again, all of the information you need is in here.

I will give you 20 min to read all the information, and then 60 min to work as a team to come up with a plan. *{Hand them the Final Plan form.}* That plan has to include: any U.S. personnel who will be involved; any transportation they need to get to, from, and around the island; any weapons they will need; critical times for the mission (Onset: when they leave the base or ship – NOT 2 AM as listed in the Mission Statement; Contact: when the rescuers come face to face with the Red Cross workers; Evacuation: the time the Red Cross workers leave the church; and Return to Base or Ship: the time they actually get back to the base or ship); a detailed plan of the rescue; and any other comments you think I should know.

At the end of the 60 min, I will score your plan. While there is <u>no right or wrong answer</u>, I will be scoring it based on how <u>realistic</u> it is. <u>Can this mission really be carried out?</u> We had three military experts work together to come up with their ideal plan. We cannot expect you to come up with the same plan they came up with, but when they were developing their plan, they hit on some key points that, if they are not addressed, no mission can be successful. That is what I will be looking for when I score your plan. <u>How realistic is this plan?</u>

It is important to note that I am only going to score what you have written on your plan. I will be listening to your conversations, so I may know what you really meant to write – but if it is not written on your plan, I will not score it. The more detailed your plan is, the better I will understand. Filling out the plan is probably going to take longer than you think it is. Be sure to allow enough time to fill it out.

Again, I will give you 20 min to read the binders to yourself. During that time, you are welcome to take any notes you want, but you are not allowed to talk to each other at all during that time. After the 20-min reading time, you will have 60 min to work together to come up with a plan. You can have your binders with you, but please do not hand your binder over to your teammate. You are more than welcome to share whatever information is in there – but think of it as information in your head.

Before you begin, I want to read the Mission Statement to you. I apologize for reading out loud to you, but it is important everyone understands what the goal is. *{Have them follow along in their binders while you read.}*

Any questions?

Experimenter after 20 min:

Remember, you have a maximum of 60 min to come up with your Final Plan. If you finish before that time, just let me know.

Any questions?

APPENDIX G
EXAMPLE OF A FINAL PLAN FROM THE NEO SCENARIO

Final Plan

PERSONNEL	TRANSPORTATION	WEAPONS
Navy Seals *US Army S.F.* *Crew to fly C-130*	*Seahawk* *C-130 to refuel Seahawk*	*On Seahawk:* *2 machine guns* *Missiles for air-to-air and air-to-ground support* *On C -130* *2.62 mm mini-guns* *40 mm cannons* *105 mm cannon* *Seals* *2 riflemen w/ M-16 rifles.* *2 riflemen w/ M-16 rifles and grenade launchers* *Night Vision*

Page 1 of 2

Group: ____________
Date: ____________

CRITICAL TIMES

1. **Onset:** 4 a.m.

2. **Contact:** 5:06 a.m.

3. **Evacuation:** 5:45

4. **Return to Base or Ship:** 6:54

DETAILED PLAN

4 a.m. leave USS and fly to church. Have SEAL Team fast rope down. Hoist red cross and team aboard. Fly out toward Army base. Have C-130 meet @ 6:30 for refuel. Land on Army base @ 6:54.
Local military try to keep rebels busy and out of area if possible.

ADDITIONAL COMMENTS

Riflemen and night vision to hold off any rebels who may get through.

Flight @ night to avoid detection

SEALS – Smallest # of all medics

Medical attention as soon as hoist is complete.

Can defend themselves w/ weapons

Page 2 of 2

APPENDIX H
NEO SCENARIO INFORMATION UPDATE: DYNAMIC KNOWLEDGE CONDITION

NEWS ALERT !!!!!

1. Intelligence reports indicate that the enemy forces have taken control of the village. Enemy strongholds now extend from the northern tip of the island, southward for 75 miles.

2. The fog encompassing the island will lift at 0900 (9 am).

3. Enemy patrol boats have been sighted off the eastern-most point of the island. While the patrol boats can travel at speeds up to 30 mph, they appear to be staying along the shore, within 15 miles to the north and south of the eastern tip.

APPENDIX I
IDEAL SOLUTION TO THE NEO SCENARIO

Solution:

- Key Points:
  - Covert operation
  - Conducted at night, during high tide
  - Use Navy SEALs and Marine CH-53 (does not need refueling)
  - Weapons: M-16 rifles and grenade launchers
2. 1800 hr: SEAL team leaves USS ENTERPRISE on a CH-53.
3. 1900 hr: SEAL team drops from a height of 500 ft into the ocean with two inflated Zodiacs. The drop is 12 miles off the shore (over the horizon. The CH-53 returns to the base or USS ENTERPRISE for refueling.
4. 2000 hr: SEAL team reaches the shore and hides the Zodiacs. Proceeds to the church, being careful to stay off the roads because of possible mines.
5. 2045 hr: Reaches church, makes contact with workers.
6. 2100 hr: Leaves church, carrying wounded and providing medical care along the way.
7. 2145 hr: Reaches shore. Uses the two hidden Zodiacs to motor out 12 miles.
8. 2245 hr: Rendezvous with CH-53 (altitude: no higher than 250 ft). Airlifts workers onto the helicopter. SEAL team sinks Zodiacs.
9. 2345 hr: Return to USS ENTERPRISE for additional medical treatment.

APPENDIX J
DEFINITIONS AND EXAMPLES FOR THE MACROCOGNITIVE MAJOR PROCESSES

A.) **Individual Knowledge Building:** Individual team members ***ask*** for clarification of data or information, or ***respond*** to clarification requested by other team members.

- "I am the environmental expert." (*if someone asked who had information about the weather)*
- "Where do we write up our final plan?"
- "We have 30 min remaining." (i*f someone asked how much time was left to do this*)
- "Don't they have a translator?"
- "I don't think anyone has a translator for Draponize."

B.) **Team Knowledge Building**: ***All*** team members participate in ***clarifying information*** (e.g., answering a question) to build team knowledge**. (NOT solution options.)**

- "Are there windows in the church?" (E)
- "Eight windows in the church." (W)
- "Eight windows." (I)
- "The only problem is they are not going to do us any good because they (workers) are in an inside room." (I)
- "Let's see. The fog starts at 6?" (W)
- "Yes, it does, and it'll last until noon." (E)
- "And you had said there's heavy fog and light drizzle too." (I)
- "Yeah, all day." (E)

C.) **Developing Shared Problem Conceptualization:** Team members ***sharing their understanding*** of problem goals, characteristics of the environment and rules for operating the generation of quality problem solutions. **(Unlike "B", does NOT need to include all team members. NOT solution options. NOT an answer to a question.)**

Example: Goals
- "Okay. So we have 24 hr to rescue the Red Cross workers."
- "Yes, and we have about 50 min to come up with a feasible plan to do it."

Example: Characteristics of Environment
- We can only get small boats in at high tide, which is 7-9 am and 8-10 pm.

Example: Rules – Quality Problem Solutions
- "Our goal is to rescue the Red Cross workers and get in and out undetected using either the army, navy, or the marines."

D.) **Team Consensus Development: *Raising*** (see example 1.) and/or ***discussing solution options*** (see example 2) (**not necessary to include all three team members**) or ***Collective Agreement*** (see examples 3 and 4) by team members on a particular final solution option (i.e., each team member does not have to agree on the solution option but as a team they need to agree on the final solution option). **(For final solution option only: Must include all three team members, and must end in final consensus/agreement.)**

Example 1: Raising an Option

- “I’m thinking the Navy SEALS and the Marines. They can both see at night and the enemy can’t. That’s a big advantage for getting in and out undetected. Besides, they work well together.”

Example 2: Discussing Solution Options

- I think we should use an 11 man team: 7 SEAL and 4 Marines.
- Why only marines and seals?
- What do you guys think?
- Because Navy and Marines work hand and hand.

Example 3: Collective Agreement

- “I agree with the final plan.” (W)
- “I’ll go along with what we have. Although I’m still not sure why we need the Marines as well as the Navy SEALS.” (I)
- “I’m okay with our plan.” (E)

Example 4: Collective Agreement

- “I’m thinking that we use the Seahawk. It’s used for special operations and can go 395 miles without refueling.” (W)
- “Sounds good if it can fly in the fog and drizzle.” (E)
- It can fly day or night, regardless of the weather conditions.” (W)
- “That sounds good to me.” (E)
- “Yeah, sounds like a good plan to me too.” (I)
- “Okay. Seahawk it is.” (W)

E.) **Outcome Appraisal:** Team evaluation **(all team members)** of selected ***solution option*** against problem solving ***goal.*** Team revises solution option if option does not meet goal.

- “Our plan to use the Navy SEALS, Blackhawk, and the Zodiak meets all the main criteria for rescuing the Red Cross workers.” (I)
- “Agreed.” (E)
- “Okay.” (W)
- “The Navy SEALS using the Blackhawk and the Zodiak can accomplish the mission, but our plan cannot be completed within 24 hr.” (I)
- “We need to relook at the details of the plan. How about if we leave earlier?” (W)
- “That might work.” (E)

APPENDIX K
DEFINITIONS AND EXAMPLES FOR THE MACROCOGNITIVE SUBPROCESSES

Macrocognitive Subprocesses:

- **1.) Iterative Information Collection**: **Collecting and analyzing** information to come up with a solution but no specific solution mentioned.
    - "I noticed the rebels don't have night vision and it's foggy in the morning till 10 am (*data*); that's to our advantage." (*information -- no mention of specific use of this information towards the solution*)
    - "It seems we have better NVG capability than the rebels" (*providing analyzed information*)
    - **"**I think we should first start talking about our expertise." (i.e., *approach to develop a solution*)
    - "They have medical training." (*referring to the SEALS*)

- **2.) Individual Task Knowledge Development:** An individual team member ***asking*** for clarification to data or information about the task; or ***response*** to clarification ***about the task (Course of Action)***.
    - "Where do we write up our final plan?"
    - "I'm going to talk and you write that in the final plan."
    - "Do you want to do a quick game plan first?"

- **3.) Individual Mental Model Development:** Individual team member ***using available information*** to increase his/her knowledge representation of the problem situation.
    - "It's two in the morning in January and January is the rainy season for this island; the island is 750 miles north of Australia and is mostly rain forest and vegetation; can only get battleships within a mile of coral and at low tide can't get a single man raft onto the island; before noon heavy fog and by noon it will be gone."

- **4.) Team Pattern Recognition and Trend Analysis:** The team as a whole identifies a ***pattern*** of data, information or knowledge.
    - "It seems like all the **needed assets (SEALS, Blackhawk, F-18's)** are located on the USS ENTERPRISE."(E) (*needed assets are the patterned information*)
    - "Yes." (I)
    - "Yes." (W)

- **5.) Team Mental Model Development:** The increasing similarity between an individual's knowledge representation and the team's knowledge representation through the process of ***individual team members convincing other team members to accept specific data, information or knowledge.***
    - "I'm not sure about the Navy SEALS for this operation." (E)
    - "The SEALS still sound good to me. Plus they are emergency medically trained and we need that." (I)

- "Now that you pointed that out to me (about the medic). I see what you mean about using the SEALS." (E)
- "Let's go with the SEALS then." (W)

♦ **6.) <u>Recognition of Expertise:</u>** When an individual **recognizes/acknowledges** another individual as an expert and accepts specific data, information, or knowledge from that individual as true.

- "We need to arrive on the island by small boat during high tide due to the coral reefs." (E)
- "You're the environmental **expert**. So, using the zodiak, then. Just tell me what time we need to arrive and we'll go with that." (W)
- "So, where do you want to enter from?" (E)
- "That's her **expertise**." (W)
- "They enter from this part...the stairs." (I)
- "From the front or the side?" (E)
- "The front." (I)
- "So—by the stairs then." (W)
- "Yeah." (I)

♦ **7.) <u>Sharing Unique Knowledge:</u>** An exchange process where any information ***uniquely held by an individual*** (e.g., weapons information, intelligence information) is made available to all other group members **<u>and</u>** the group uses this information in their option selection process.

- "I have information on the sunrise/sunset times: 7 am/7 pm. (E)
- "We'll leave after 7 pm then. Since it'll be dark." (W)

♦ **8.) <u>Uncertainty Resolution</u>:** The progressive minimization of sources of uncertainty in a decision environment.

- "And they have—the local military has three Toyota trucks, bikes, and donkeys available for us to use."
- "Trucks are faster, but they would be able to be heard."
- "The donkeys, you never know if they're going to cooperate or not."
- "So, if you're going to rely on one of the three, I would think the bikes then."
- "Can it move?"
- "What? The forces?"
- "No, the Enterprise."
- "Oh, yeah. I assume so."
- "It's not a stationary boat?"
- "I don't think so. It doesn't really give that much information on it."
- "I was under the impression that you couldn't move it."
- "Yeah, me too."
- "Okay. Then I guess we're going to have to take something smaller from the Enterprise and use that to get onto the island."

♦ **9.) <u>Knowledge Interoperability:</u>** The **<u>process</u>** of individual team member's ***exchanging their knowledge*** of the ***problem situation*** such that ***agreement is reached*** among team members with respect to a common understanding of the topic's meaning (Implied agreement is okay as long as all three team members are involved in the conversation.)

- "So the rebel forces don't know where the Red Cross people are?"
- "Right."
- "They have no idea that they are in the church."
- "So, okay. That's good."
- "The problem is getting to the church and getting them out of the church and maybe back to the village I would think."
- "Yeah."
- "Since once you're in the village you're ok."
- "Right, so let's figure out how to get them from the church to the village."

♦ **10.) Visualization and Representation of Meaning:** *Visualization* is where individual team members use methods such as graphs and pictures ***to transfer meaning*** to other team members. *Representation* is where individual team members use methods such as note pads ***to sort data and information*** into meaningful chunks.

- "Let's use our note pads to sort the information we have into categories."
- "Let's draw out our basic timeline so far."

♦ **11.) Knowledge Sharing:** ***Pieces of information passed*** to another team member.

- "I am the weapons expert."
- "We only have 10 min left."
- "I need to know who the intelligence person is."
- "Okay, we're ready to begin."

♦ **12.) Knowledge Transfer:** The act of exchanging ***useful, actionable knowledge*** among team members. The term knowledge is defined and used according to the definition and principles of Bellinger,et al, 2004. ***Knowledge*** represents a pattern that connects and generally provides a high level of predictability as what is described or what will happen next.

- "If the water level is too low, the sharp reefs will cut the bottom of the boat. Therefore we must drop the Zodiak during high tide so that the SEALS can reach the shore without the reefs causing damage to the boat."
- "We got to keep in mind that if we use that, they got to refuel at the airport."
- "Yeah, refuel. Okay."

♦ **13.) Team Shared Understanding:** ***Discussion among all*** team members on a particular topic or data item (i.e., discussion does not involve answering questions).

- "No. We don't have a translator that speaks Draponize." (I)
- "But it says here we have a translator." (W)
- "He is highly skilled in many different languages." (I)
- "Then what you are hoping is that there is a translator on the island that speaks Draponize and another language that our translator also speaks." (E)

- **14.) <u>Critical Thinking:</u>** Critical thinking impacts decision processes and outcomes and can be indirectly measured through these: ***issues considered in an assessment of the plan, conflicting pieces of evidence identified, explanations of conflict generation.***

    - "We need to figure out the critical times when we can leave and at what time we would return by. So each of us needs to provide all the information we have about time constraints."
    - "First, we need to know which branch of the military has a translator that speaks Draponize if we're going to interact with the villagers." (W)
    - "None of the branches have a translator that speaks Draponize." (I)
    - "Okay, that could be a problem. We may not be able to use the villagers." (W)
    - "We need to arrive in the middle night so that the rebels can't see us."
    - "We can only get on the island by boat during high tide."

- **15.) <u>Intuitive Decision Making</u>:** Team members recognizing the ***situation as typical***, so they ***<u>immediately know</u>*** what course of action they will do. They ***<u>immediately know the</u>*** goals, priorities, and the steps of the course of action in the given situation.

    - "I've seen movies where they do rescues kind of like this, and in them the SEALS and Marines usually work really well together. Usually, you see them with boats and helicopters, and we have use of both."
    - "Yeah, I've seen movies like that too. SEALS do the rescue, Marines are there to watch their backs and fight off the enemy on the way in and out. Let's plan on doing our rescue the same way."

- **16.) <u>Solution Option Generation</u>:** ***Generating reasonable alternatives*** in a decision problem that satisfy the list of requirements.

    - "Let's see, we need to get our guys on the island to rescue the workers. Since the coral reefs are a problem, two possible ways around it to get us onto the island are using a helicopter to drop rescuers right onto the island, or to use the helicopter to drop the Zodiak during high tide."
    - "High tide let's us avoid the reef from 7-9 am; also there is heavy fog then with light drizzle. I'd recommend us going in by zodiac during that time frame."
    - "We have a few options to do this. Should we parachute in or take one of the navy SEAL type zodiac boats? Also, should we go through the shorter more dangerous enemy territory to save time, or should we stay inside the blue areas to get to the Red Cross workers?"

- **17.) <u>Team Negotiation of Solution Alternatives</u>:** ***Changes*** of solution alternatives by the ***total*** team to reach agreement.

    <u>Weapons Example</u>:

    - "So now we're only using the F-18 for backup cover." (E)
    - "F-18 is just on standby." (W)
    - "Yes, that's the new plan." (E)
    - "Used to take out oncoming enemy threat." (I)

- **18.) <u>Feedback Interpretation</u>:** The ***whole*** team discusses the selected solution option against meeting the problem goal resulting in either completely meeting the goal or areas that need to be discussed further.

    - "Our plan meets the 24 hr rescue requirement with minimum enemy contact." (I)
    - "Agreed." (W)
    - "Yes" (E)

- **19.) <u>Replanning</u>:** ***Changes*** made to the **initial plan** until the final plan is achieved. <u>Note</u>: initial plan is defined as the preliminary course of action developed by the team. All behavior leading up to the initial plan is not included in the replanning measure.

    - Okay, so our rescue plan doesn't meet the 24 hr guideline. We'll just make a few changes."
    - "Since we need to be back within 24 hr, let's just leave earlier…just so long as it's still dark out."

<u>Macrocognitive Secondary Measures:</u>

- **20.) <u>Building Common Ground</u>:** Common ground equals the amount of ***redundant terms*** (x) emerging within the group activity over the ***total number of words*** (n) generated by the group (i.e., CG = x/n; whereas the lower the number the greater the common ground among the team). **Or *BCG = (# 4 + # 5 + # 6 + #8 + # 9 + # 13 + # 17)/(Total # Utterances)***.

- **21.) <u>Mental Simulation:</u>** Individual team members or the whole team using their mental models (i.e., individual or team, respectively) to run a mental simulation of what might happen over time. Pattern matching between features of the current situation and those of previous similar situations in order to base projections on the outcomes of the current situations. Measures of mental simulation *content* could include pre/post session questionnaires, and concept maps; mental model occurrence measures could include detection of communication utterances describing comparisons to similar problems and projections about current problem. **Or MS = Out of all # 3 and # 5, see which ones have "...what if...." type statements. Tag these as MS then total these to come up with MS score and divide by the total # of Utterances.**

- **22.) <u>Storyboarding:</u>** The process of visual thinking and planning, which allows a team to brainstorm together. In addition, the team can place and arrange their ideas on cards before taking action. Measures for effective storyboarding include counting the number of cards/utterances necessary for explaining a concept or idea. **Or SB = (# 1 + # 3 + # 7+ # 12 + # 16 + # 19)/(Total # Utterances).**

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